ATLAS cosmic ray results

— Assessing the detector performance —

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On behalf of the ATLAS Collaboration

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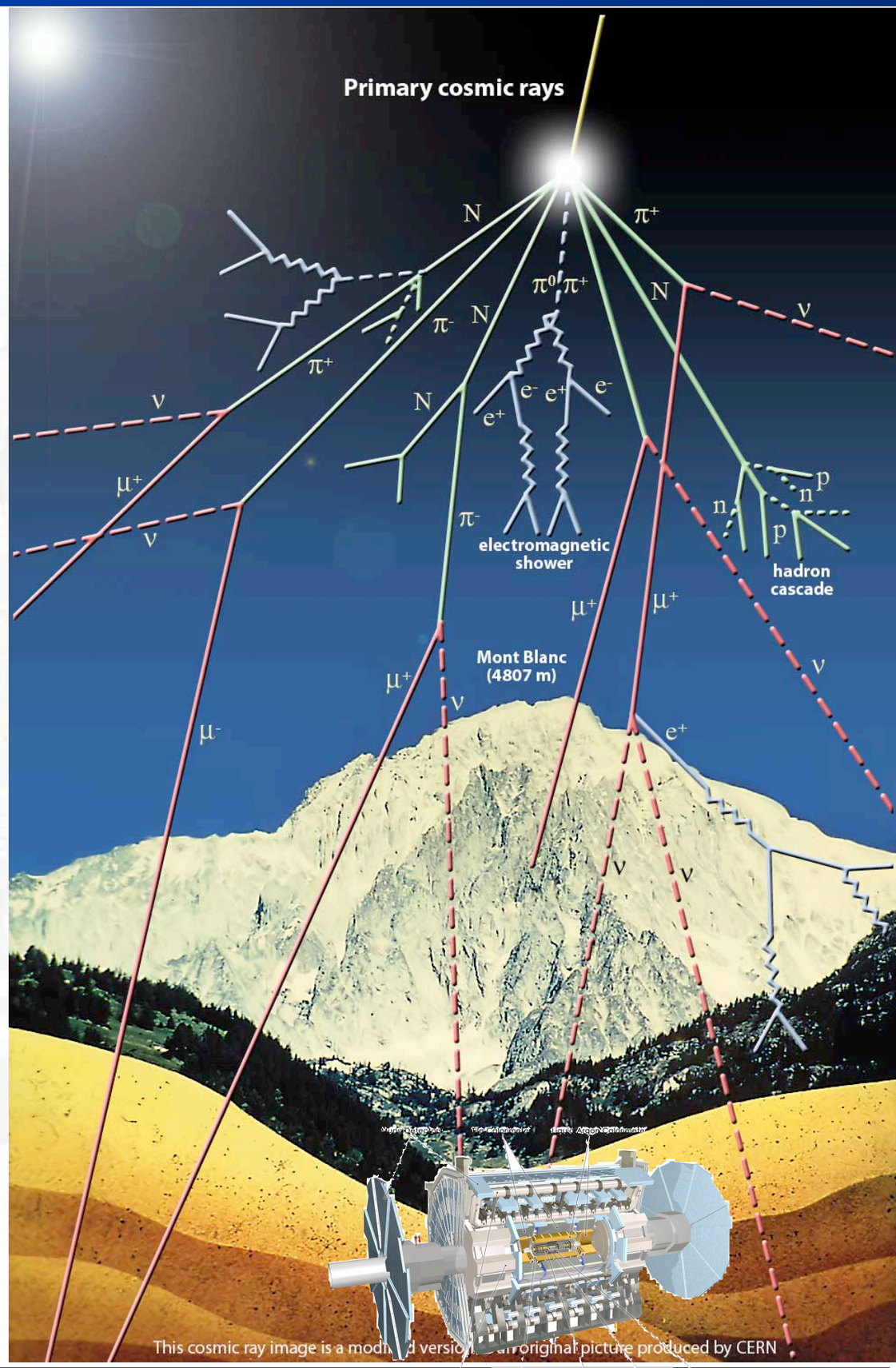
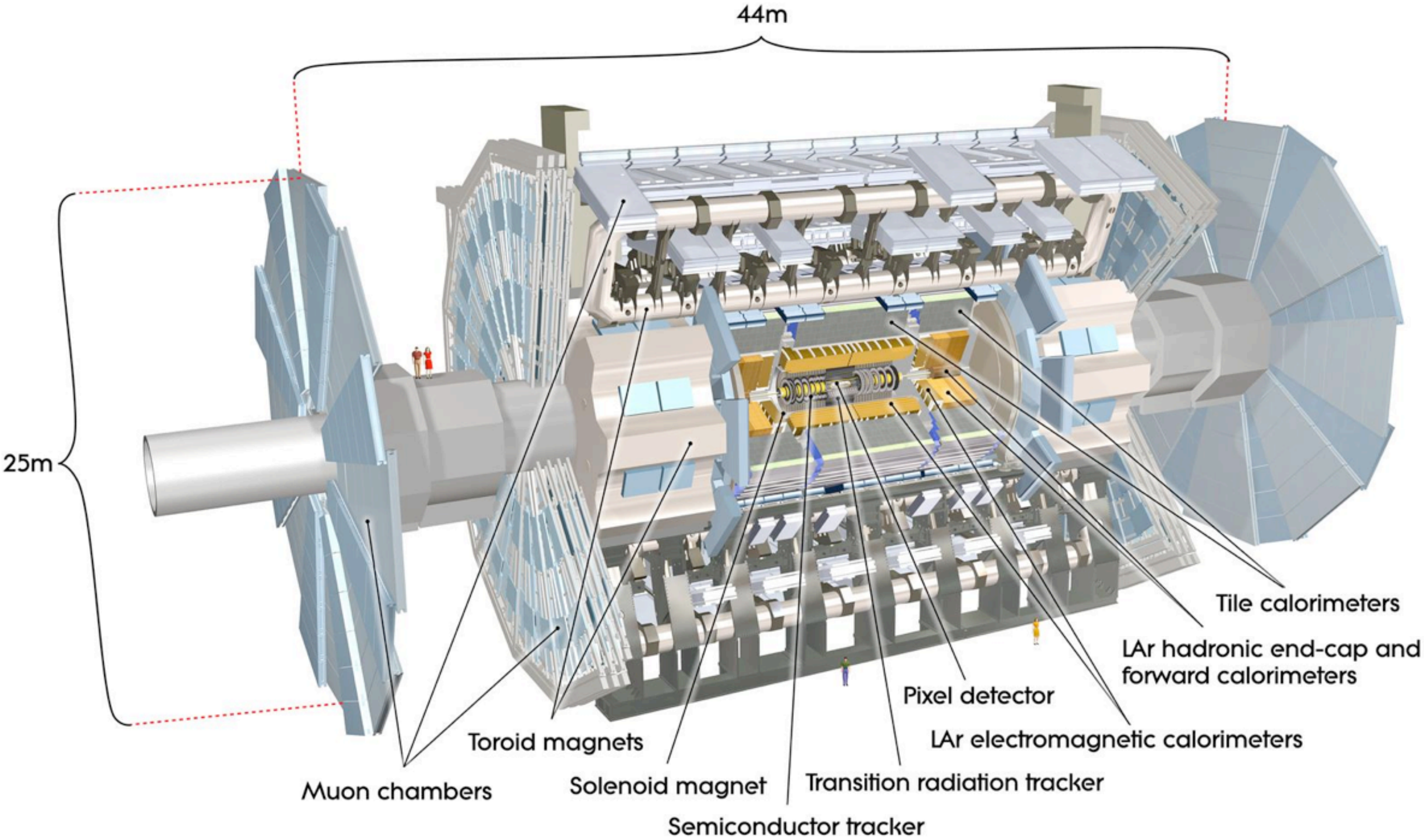
Outline

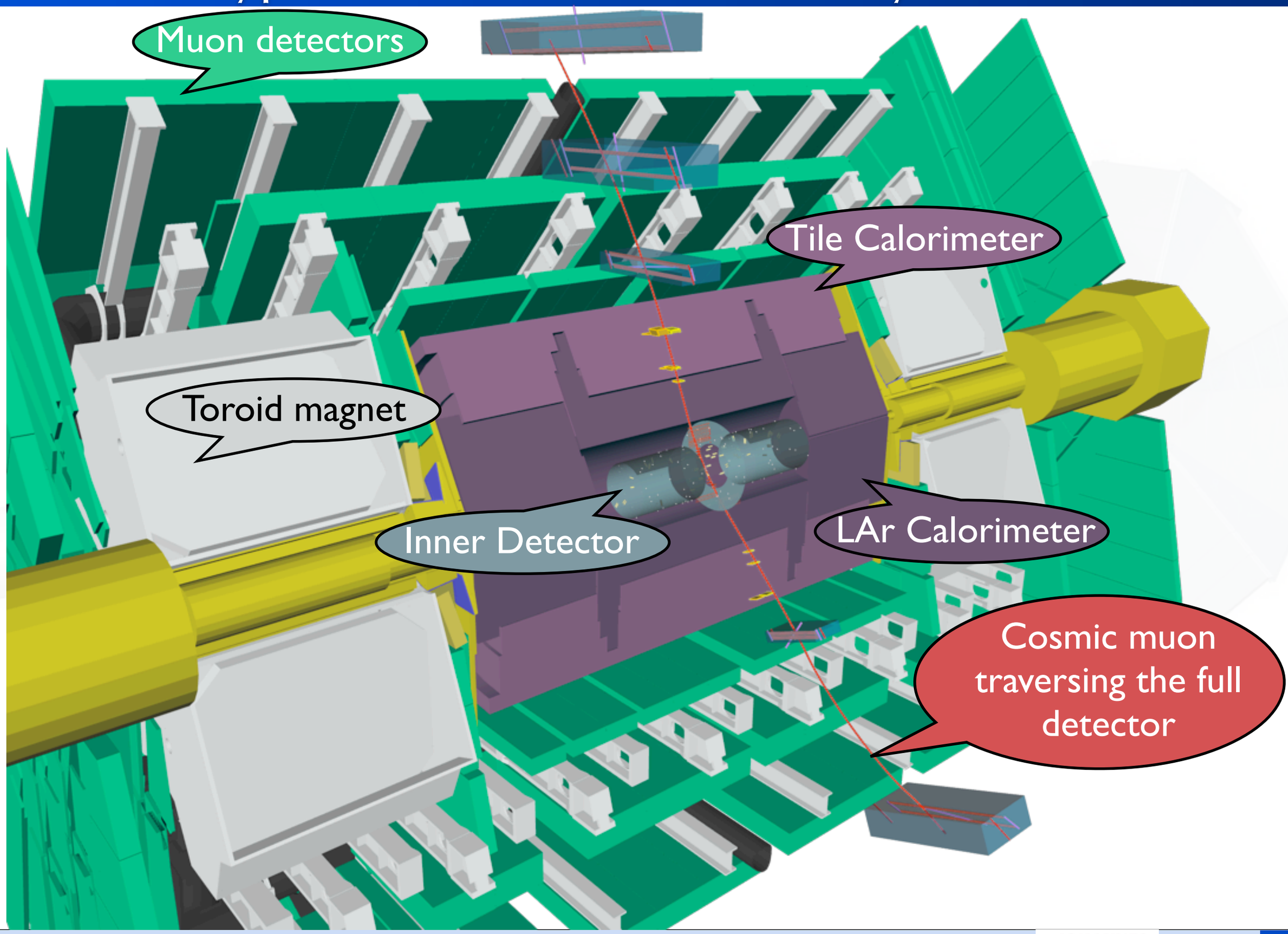
- The ATLAS detector seen by a cosmic ray muon
- Recording cosmic ray data: Trigger and Data sample
- Subdetector commissioning with cosmic ray data
- Testing object identification and reconstruction
- Summary & Outlook



The ATLAS Detector

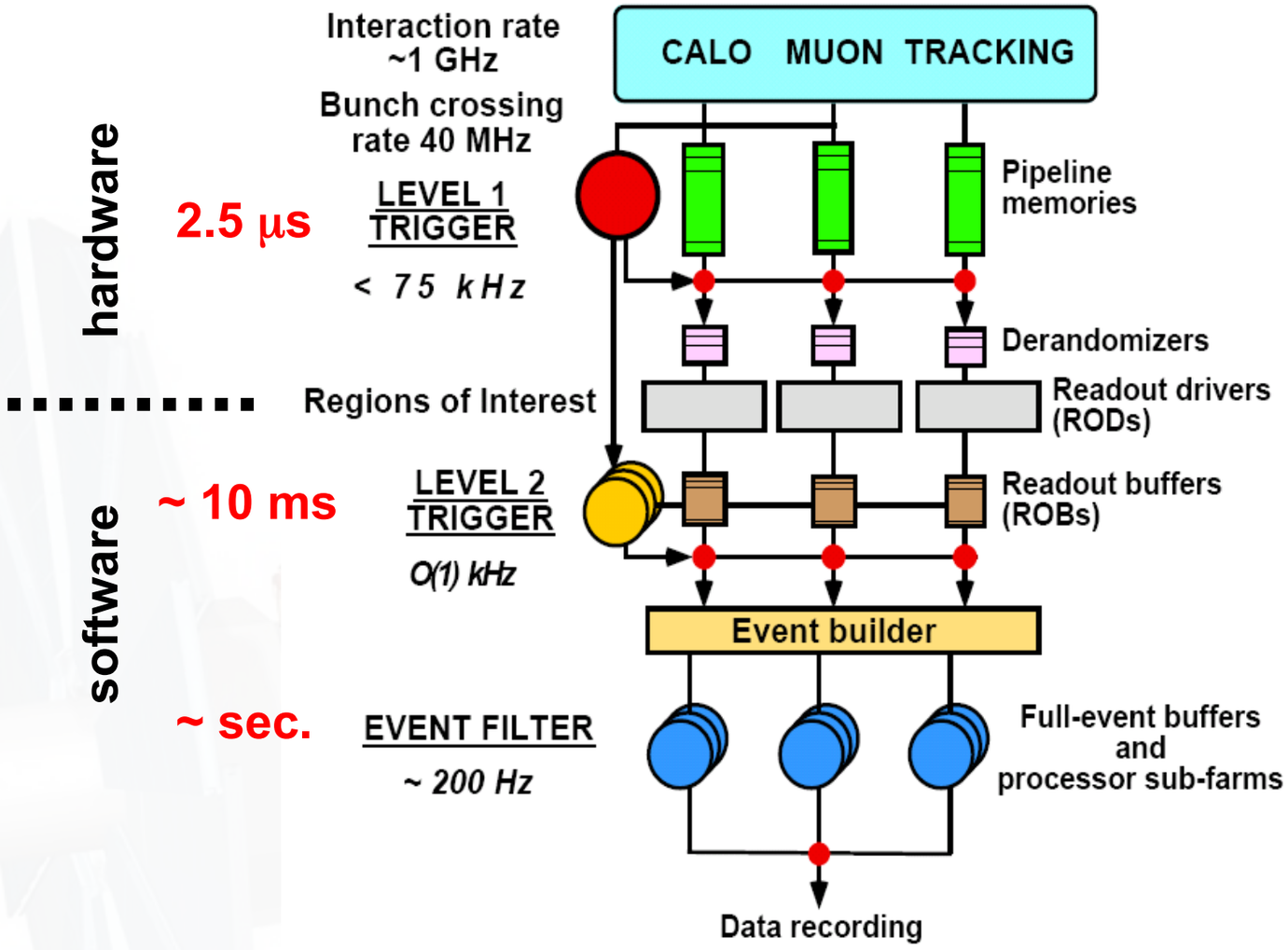


A “typical” cosmic event seen by ATLAS



The ATLAS Trigger system

3-Level Trigger System:



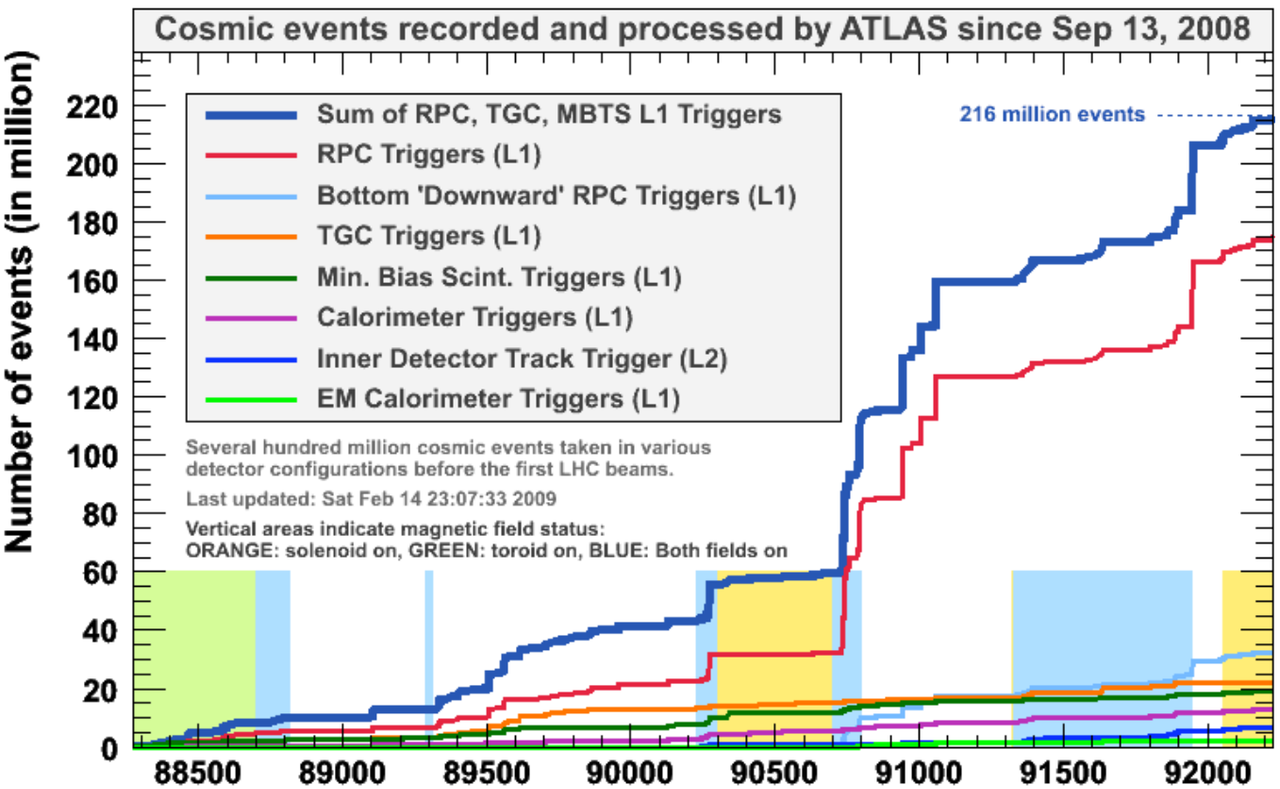
1) **LVL1** decision based on data from calorimeters and muon trigger chambers; synchronous at 40 MHz; bunch crossing identification

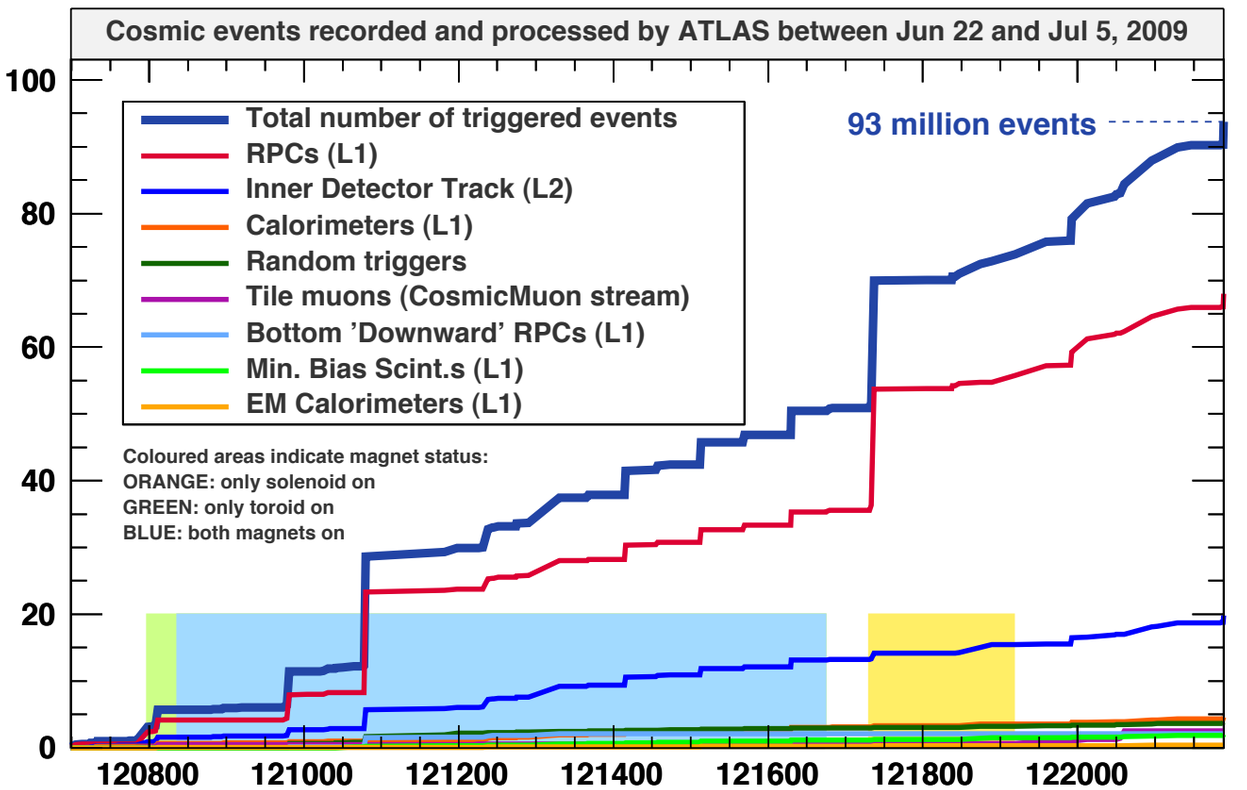
2) **LVL2** uses Regions of Interest (identified by LVL1) data (ca. 2%) with full granularity from all detectors

3) **Event Filter** has access to full event and can perform more refined event reconstruction

- Full chain exercised during cosmic data taking
  - Rate of cosmic ray events: 1-700Hz (varies with sub-detector size and location)
  - Level 2 actively selecting/rejecting events based on track reconstruction in the Inner Detector to maximize statistics of events crossing all detectors

Available data sample for cosmic analyses

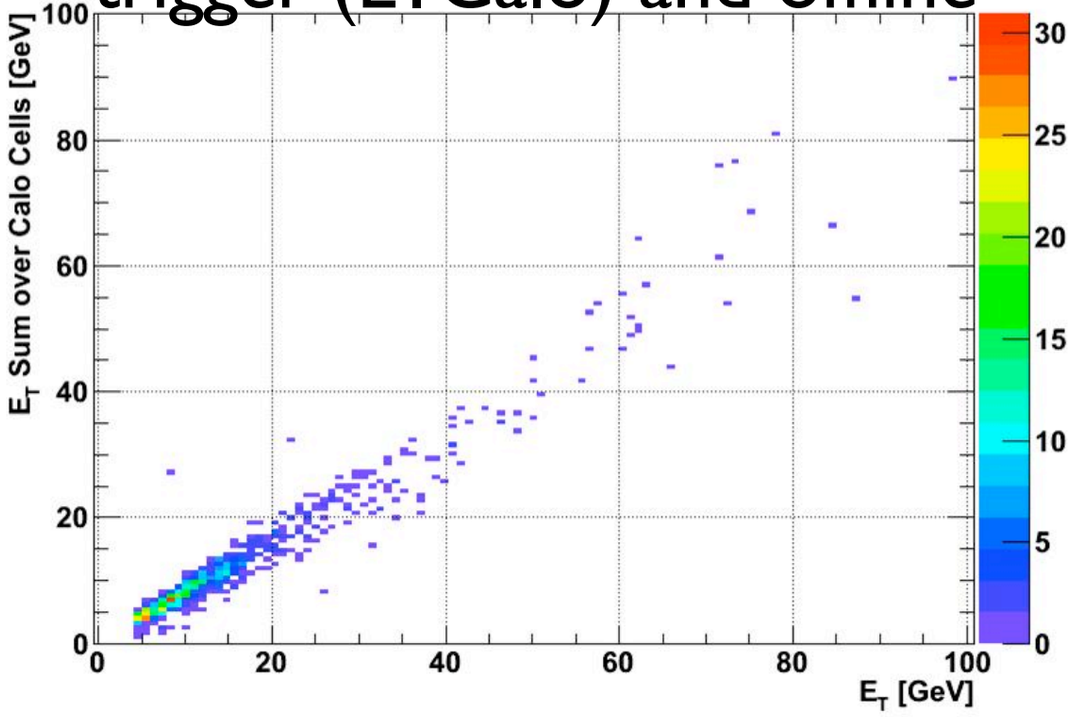




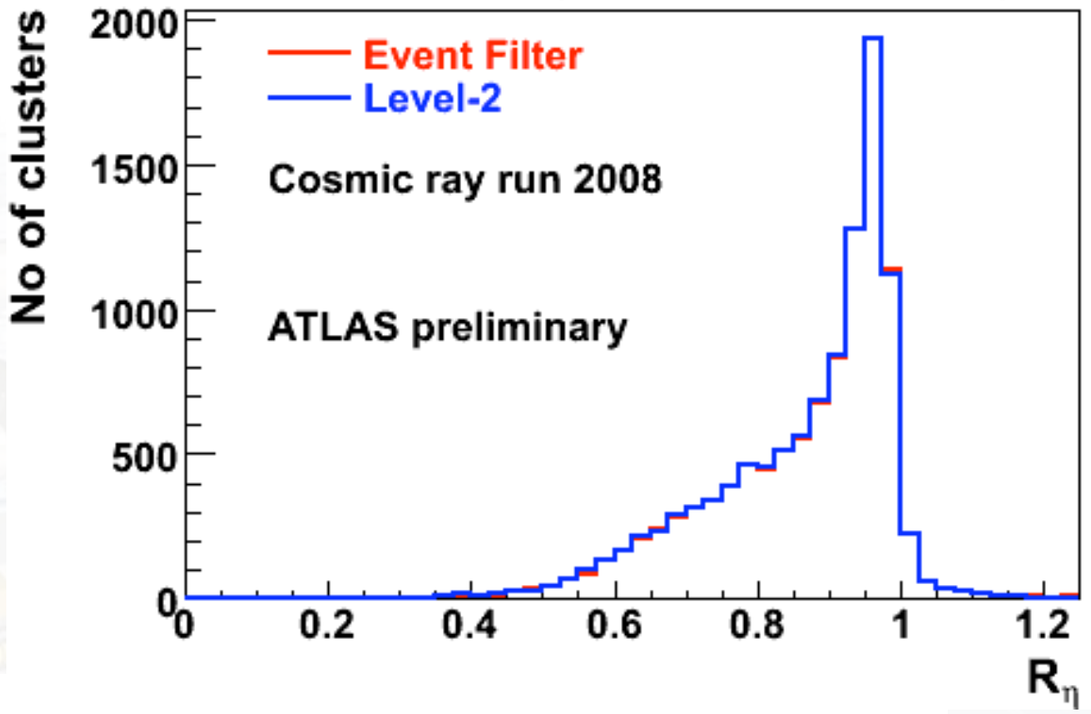
- Two major cosmic data taking periods with full detector
  - **Autumn 2008:** More than 200 million events, data went through two reprocessing cycles to further improve the quality of the data (e.g. improved calibration, reconstruction software, …)
  - **Summer 2009:** More than 90 million events, one fast reprocessing to unify reconstruction software release and apply first improved calibration and alignment constants

Trigger

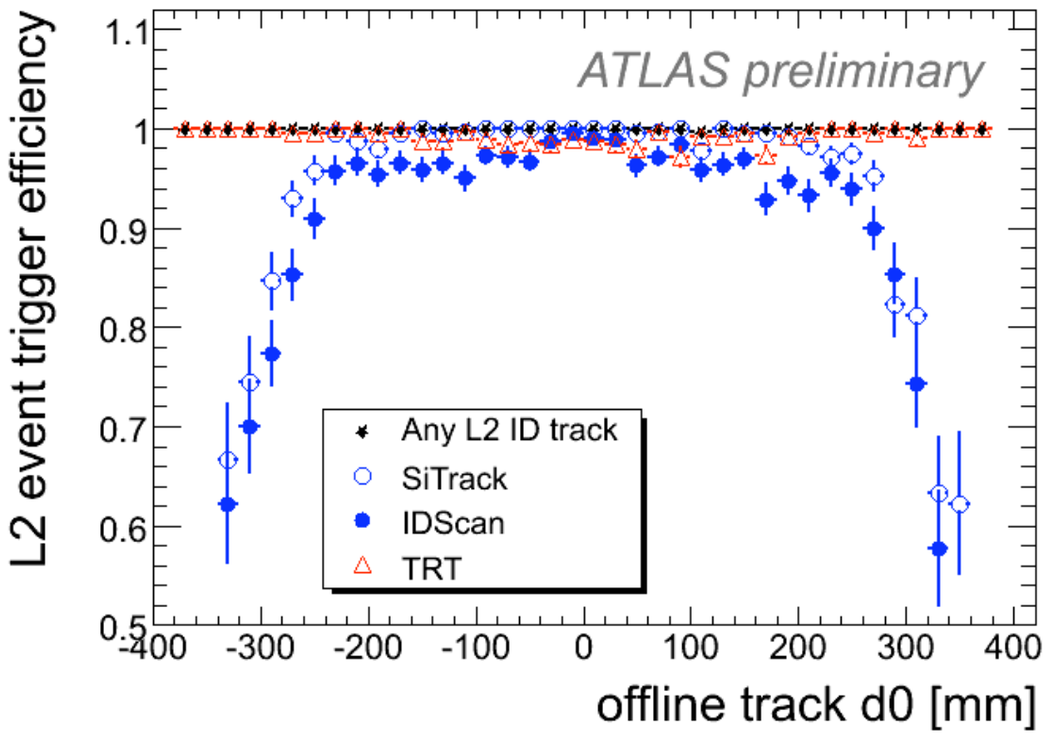
Correlation between calorimeter trigger (L1Calo) and offline

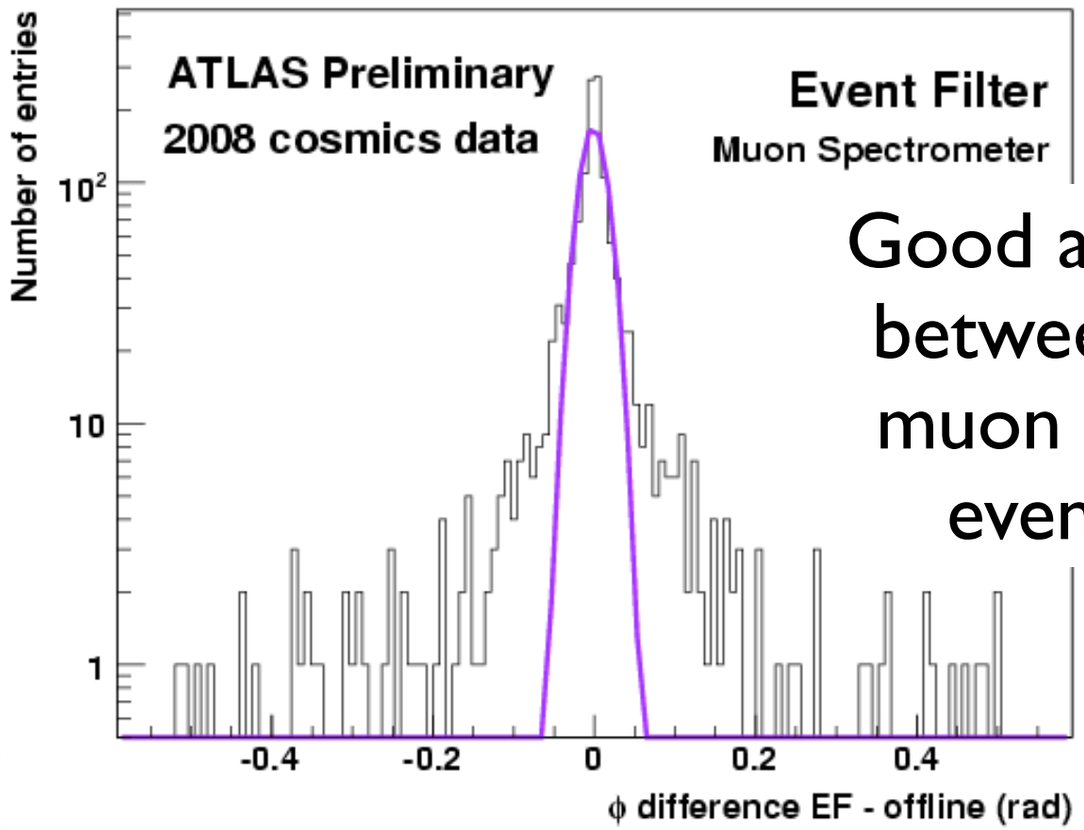


Very good agreement between L2 and event filter (electron slice)



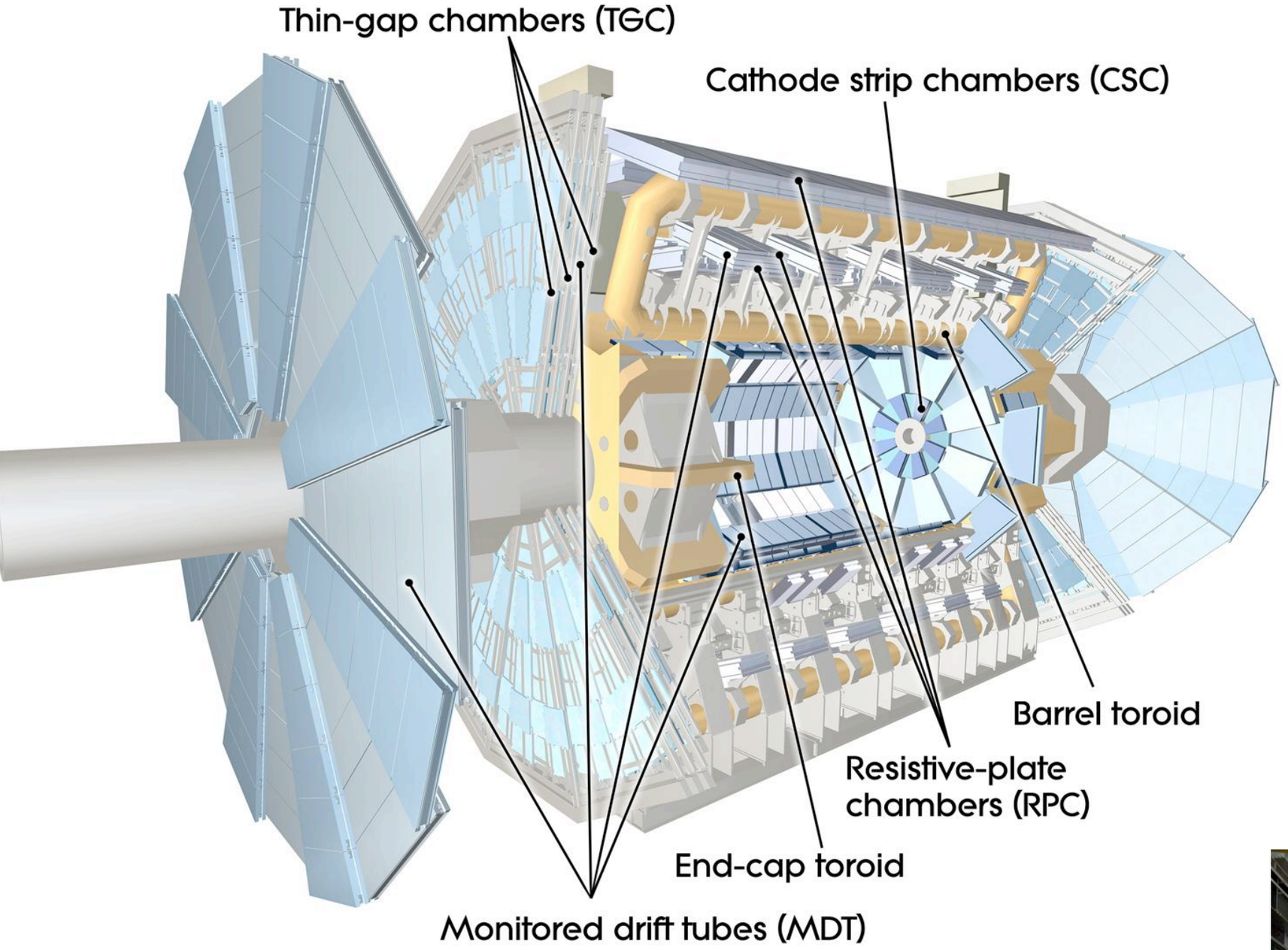
Track trigger efficiency at L2





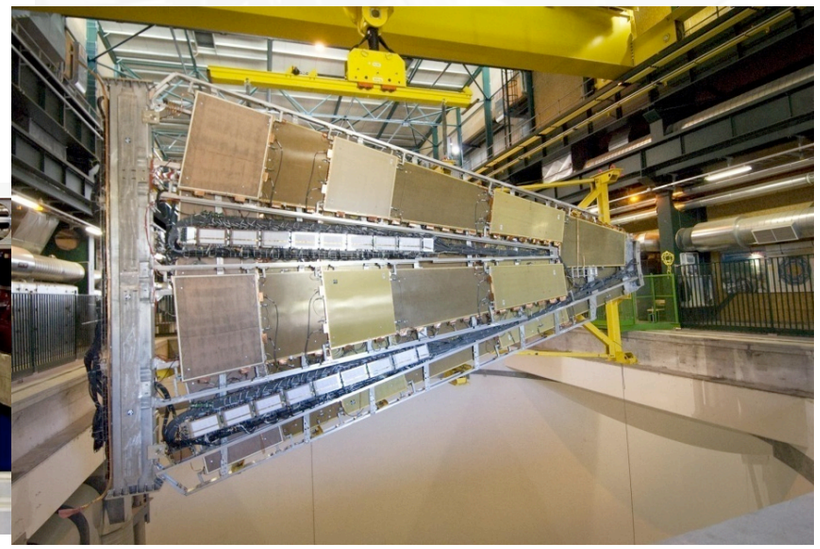
Good agreement between offline muon reco and event filter

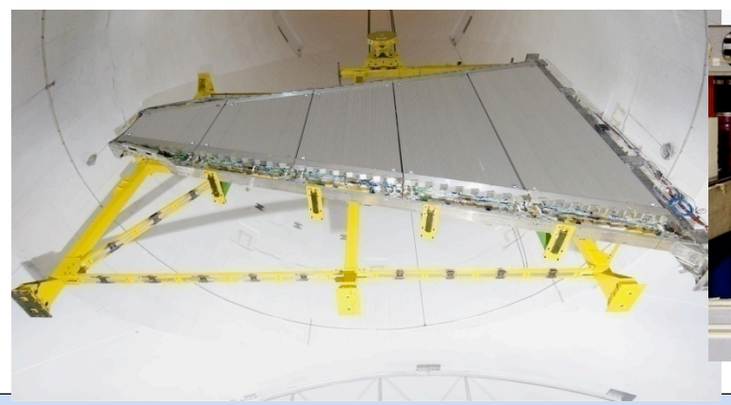
The ATLAS Muon system

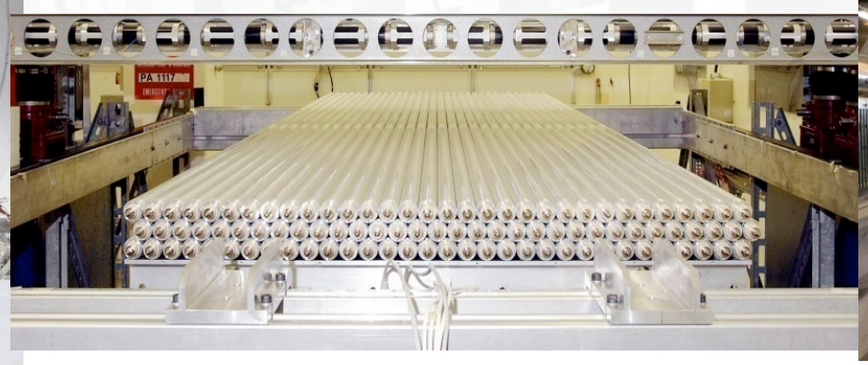


Stand-alone momentum resolution
$\Delta pT/pT < 10\%$
up to 1 TeV

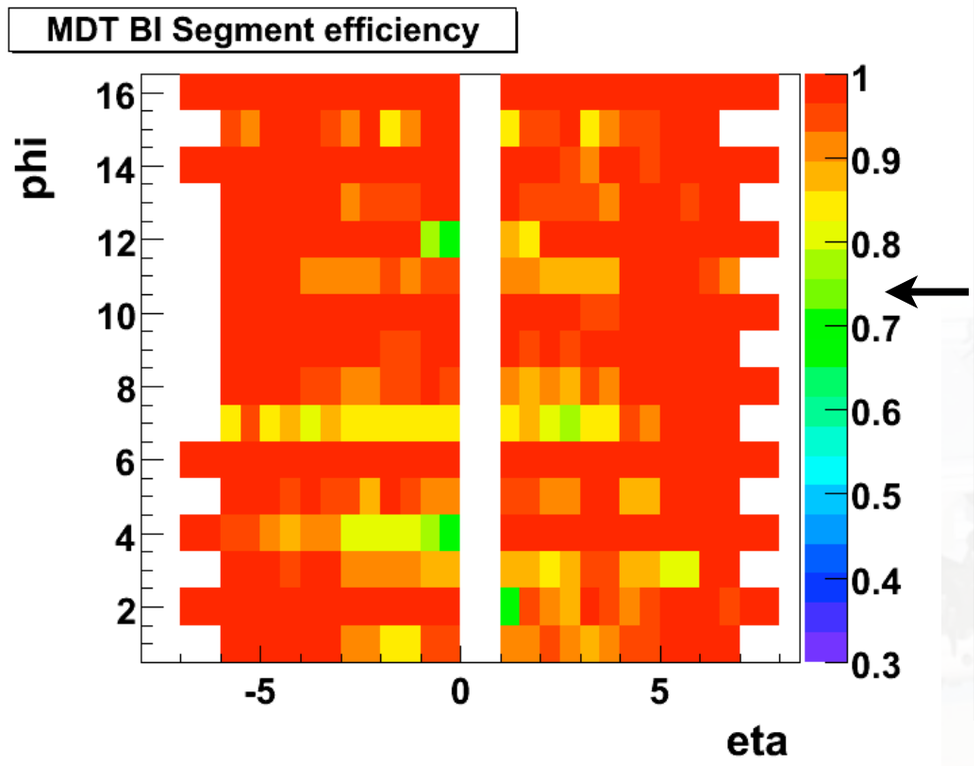
2-6 Tm $|\eta|<1.3$
4-8 Tm $1.6<|\eta|<2.7$





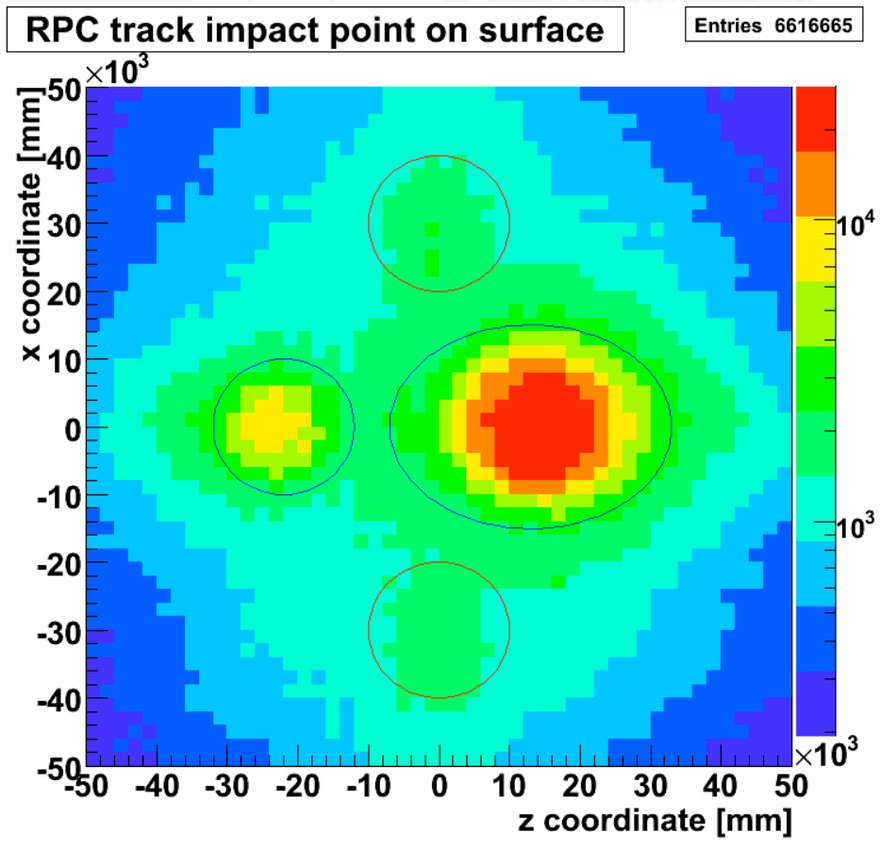


Muon Spectrometer

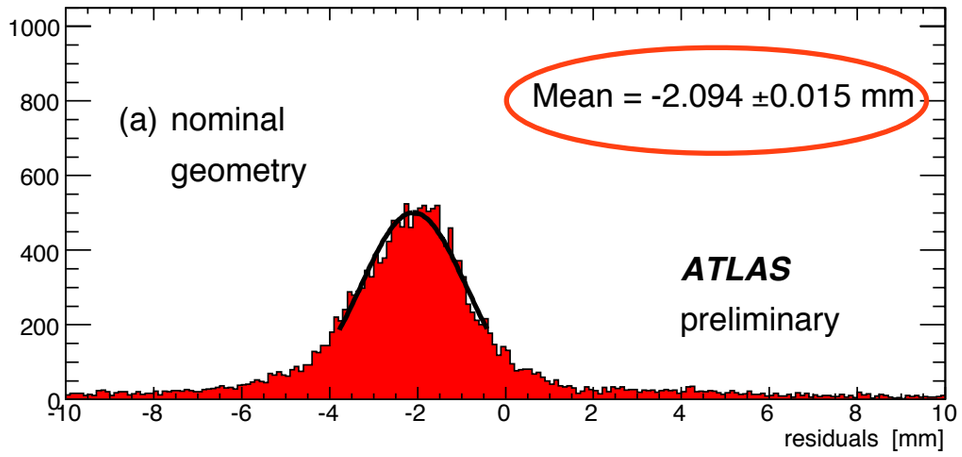


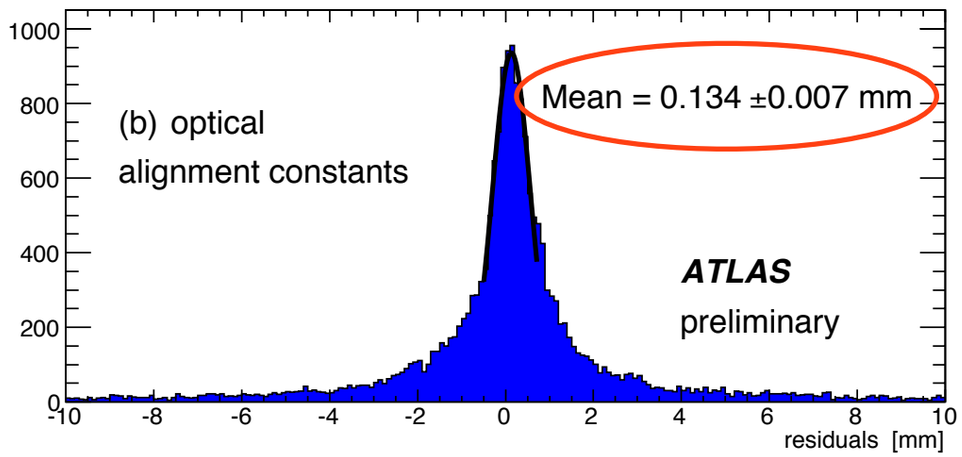
Segment efficiency map for the innermost **M**onitored **D**rift **T**ube (MDT) layer

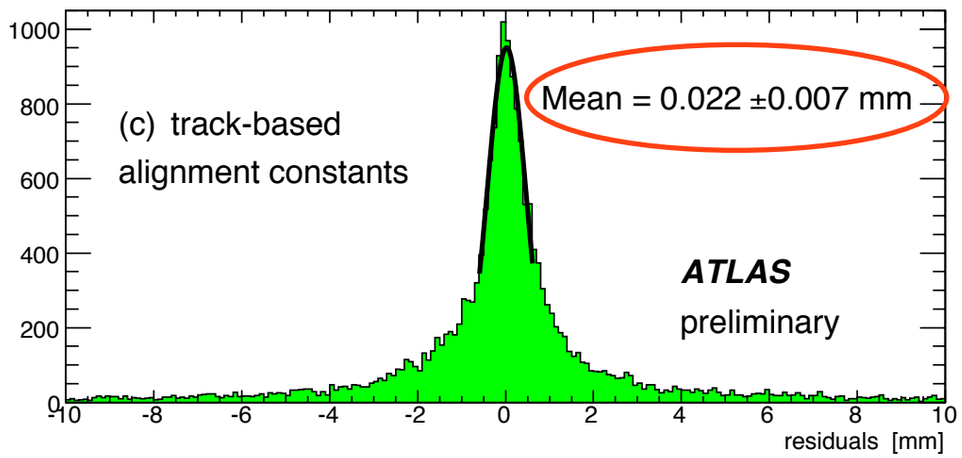
Standalone tracks from hits in the **R**esistive **P**late **C**hambers (RPC) extrapolated to the surface: the four shafts are clearly visible



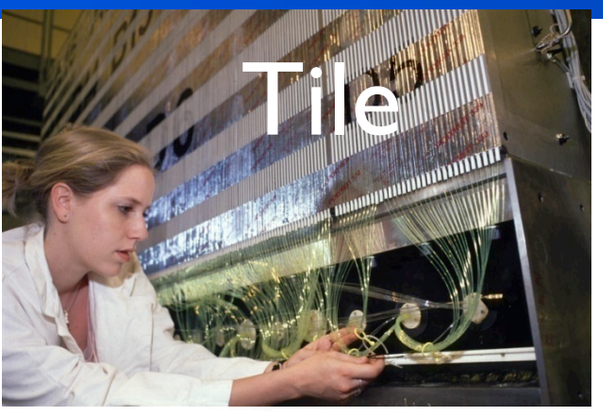
Alignment improvements (top sectors, field off)

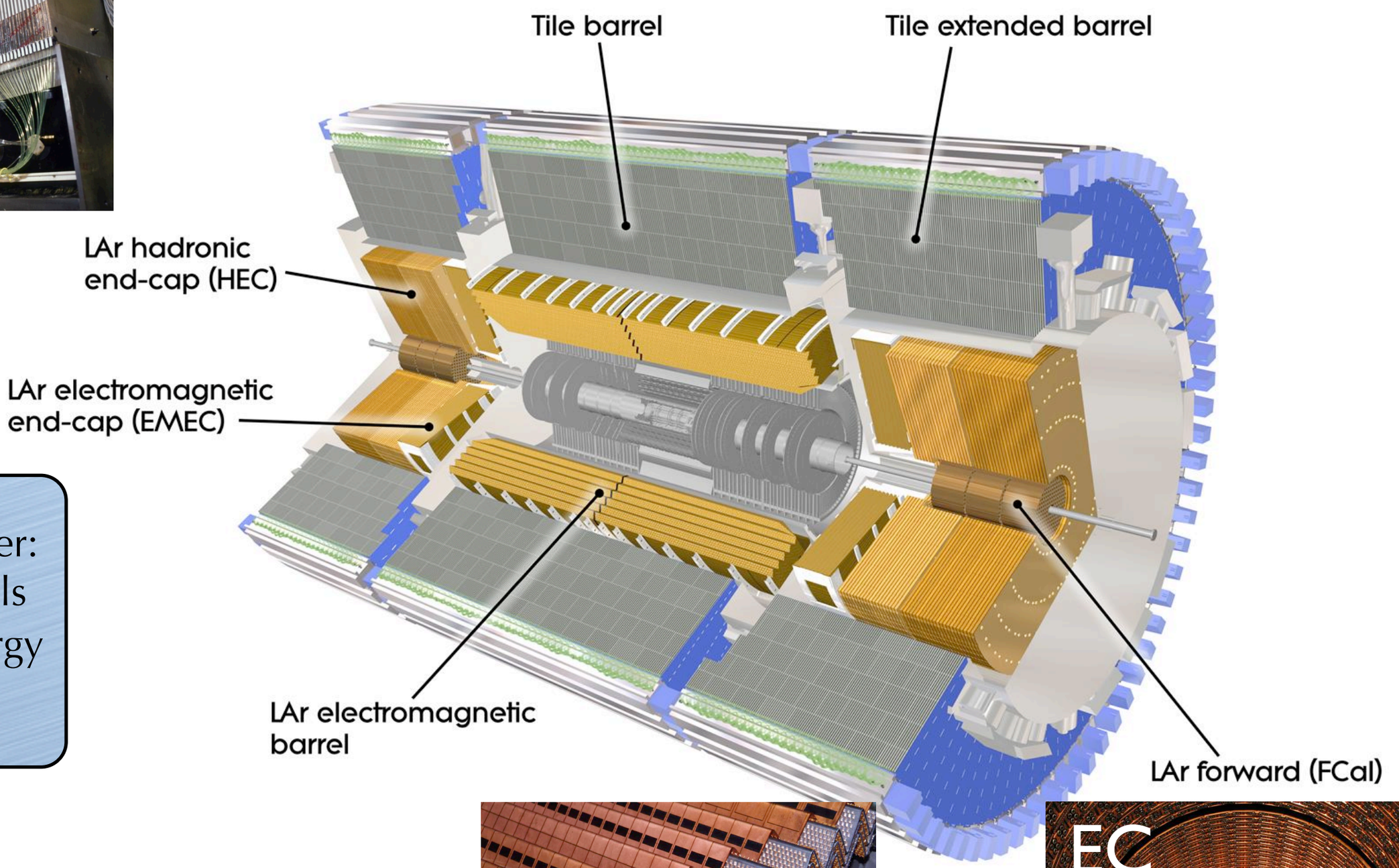






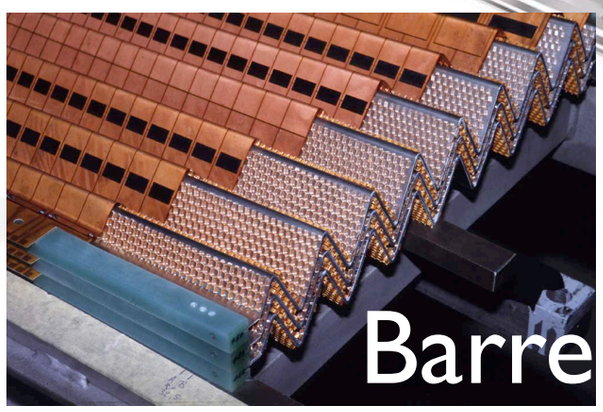
The ATLAS Calorimeters





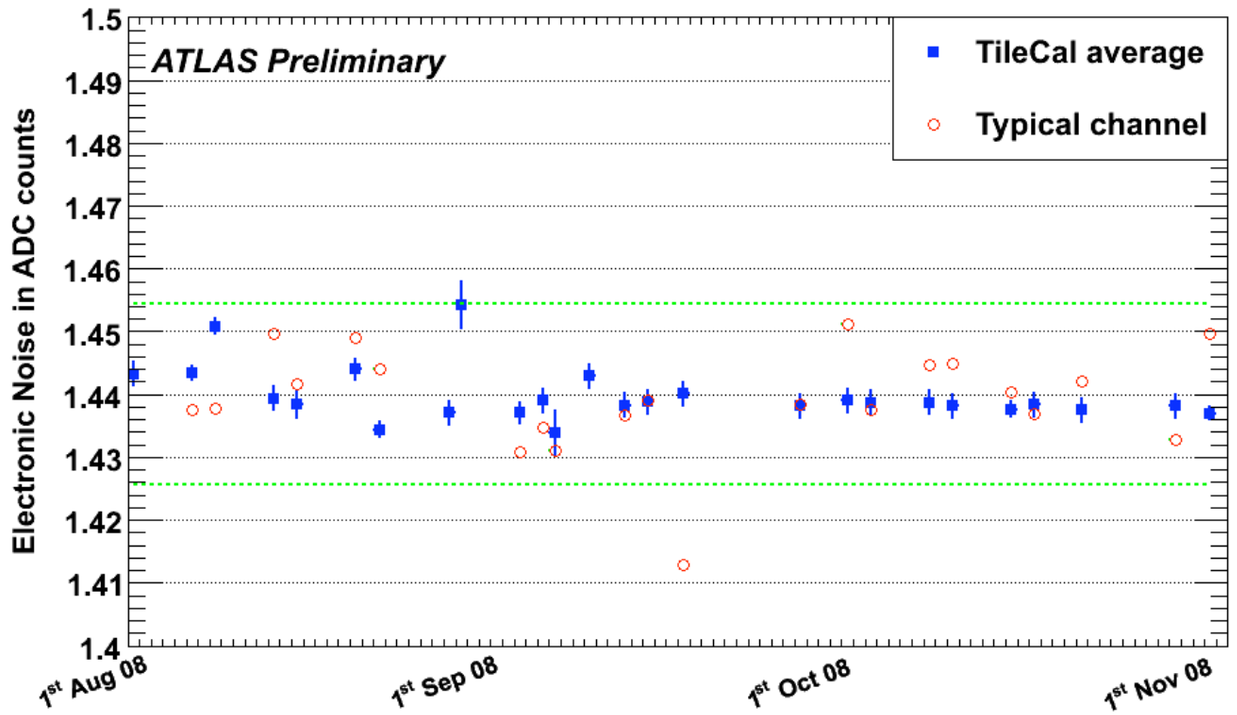
EM calorimeter:
180k channels
~10%/√E energy res. for e/γ

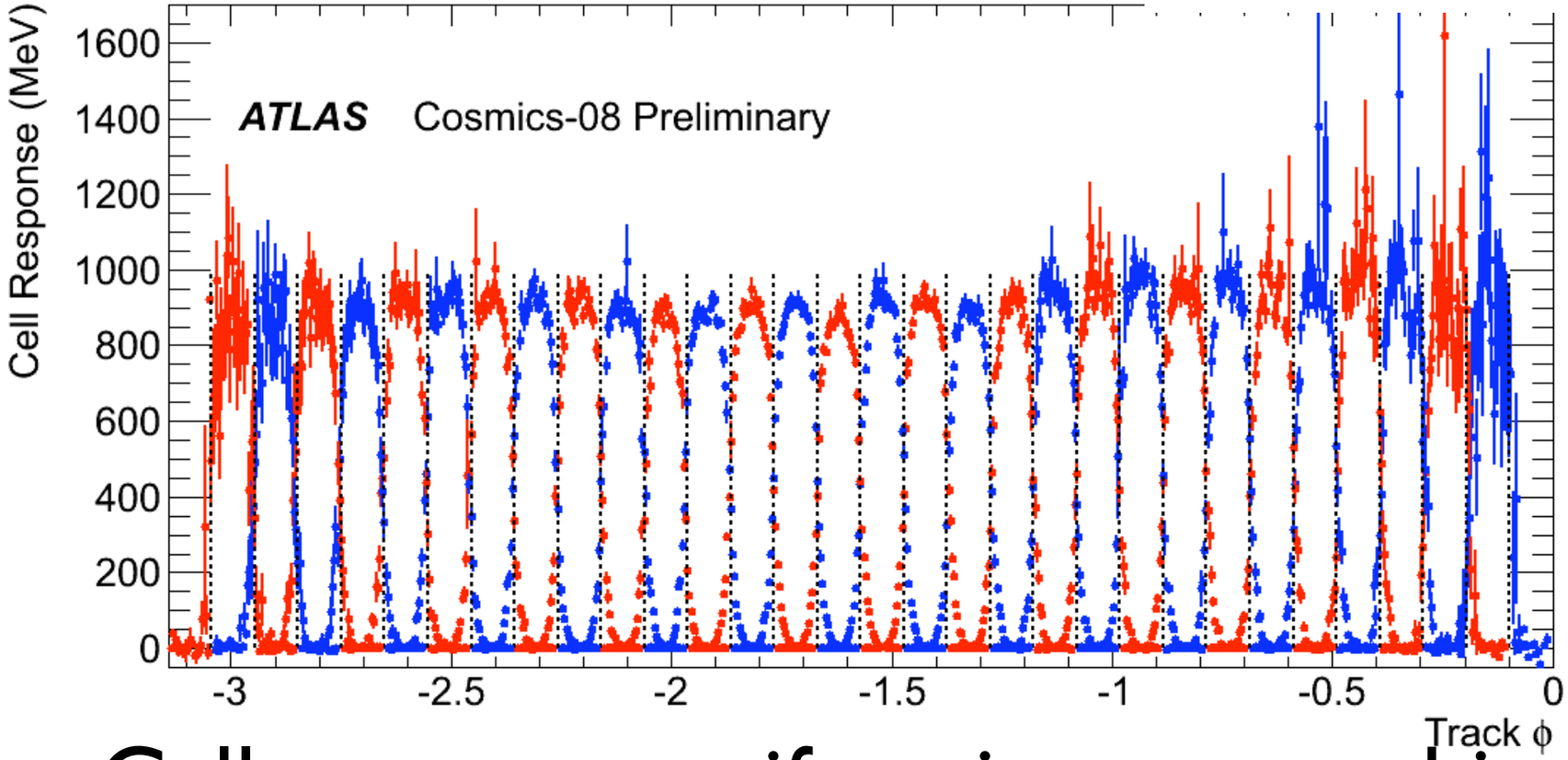
Had. calorimeter: 20k channels
σ/E ~60%/√E ⊕ 0.03 (10λ) for jets



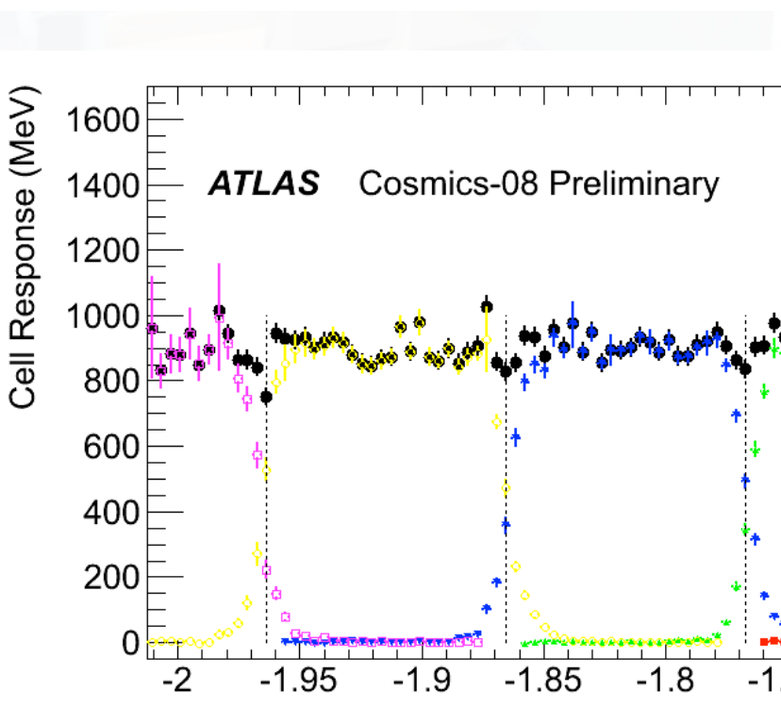
Calorimeters (Tile)

Electronic noise in Tile Calorimeter is stable over several month (based on random data)





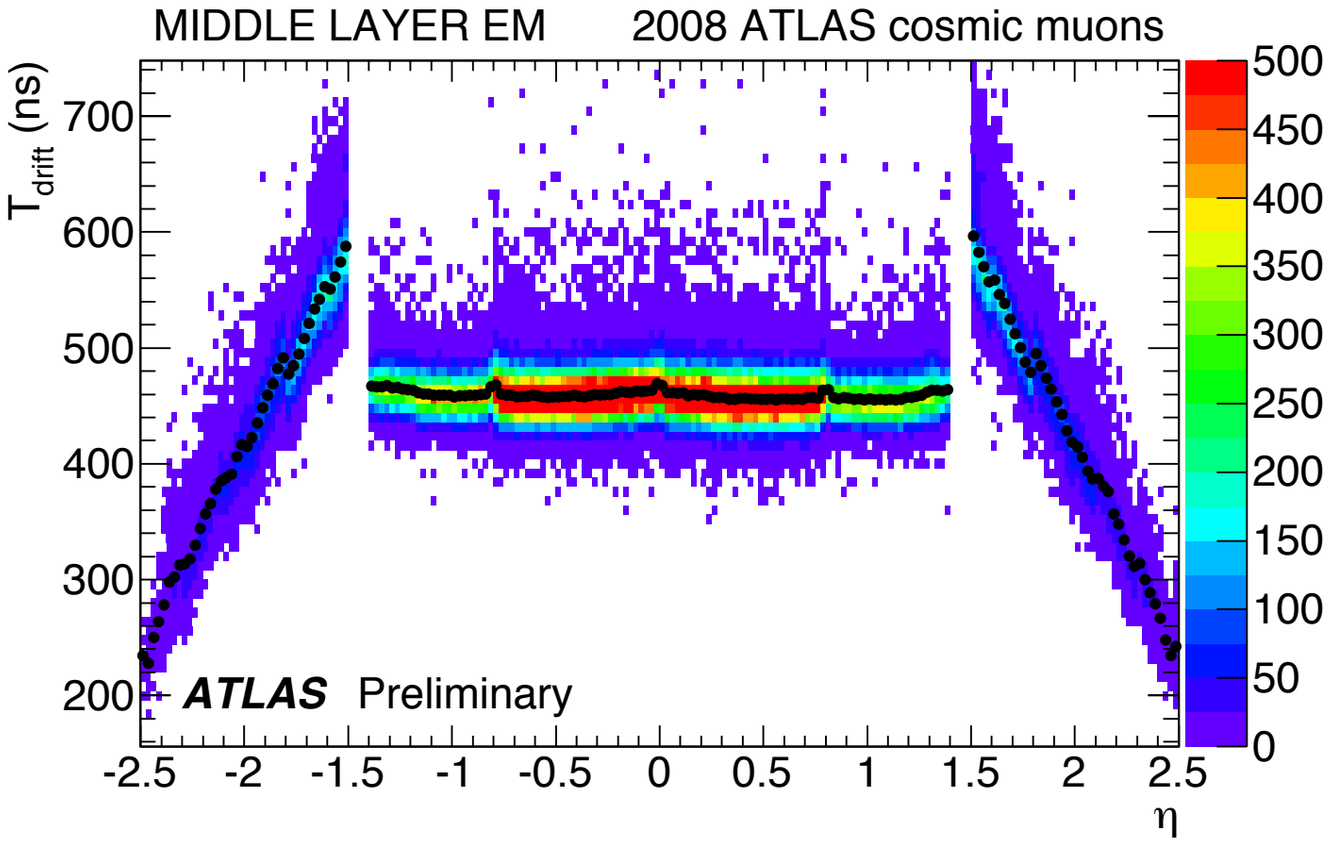
Cell response uniformity across phi

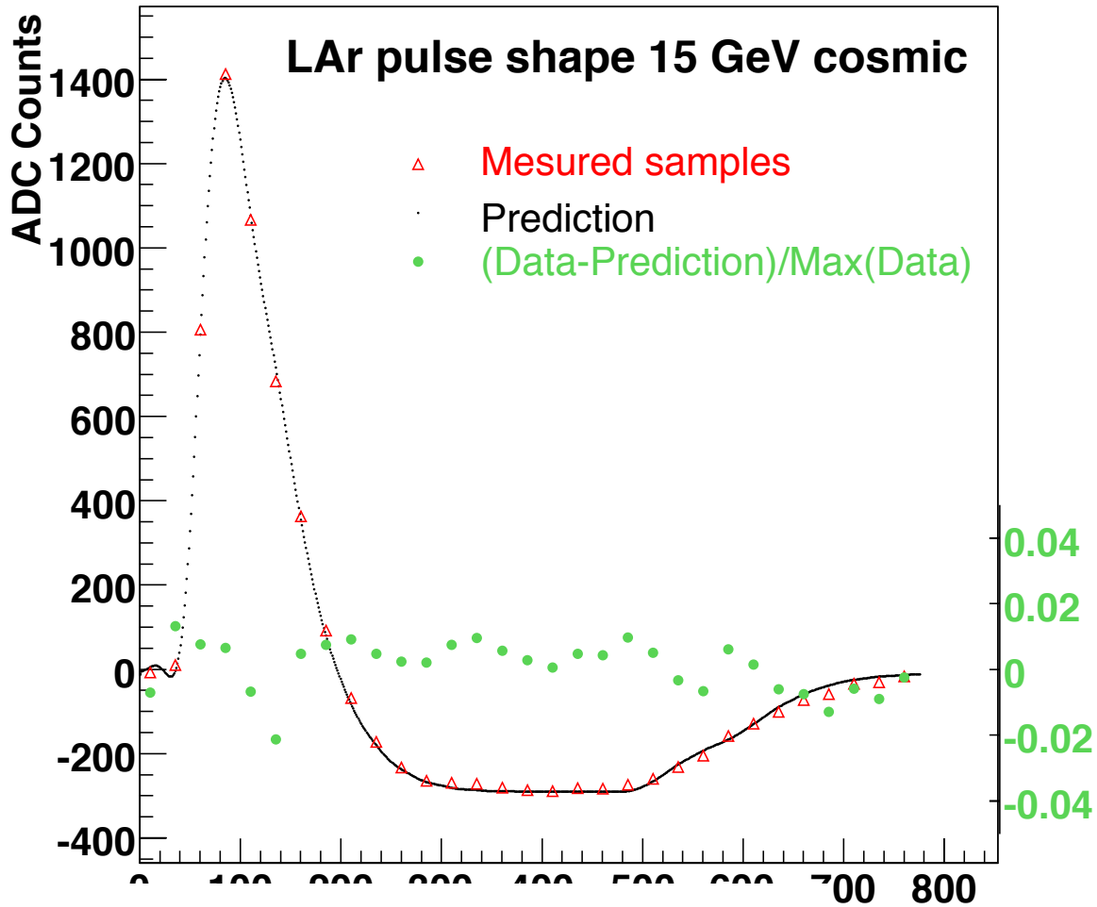


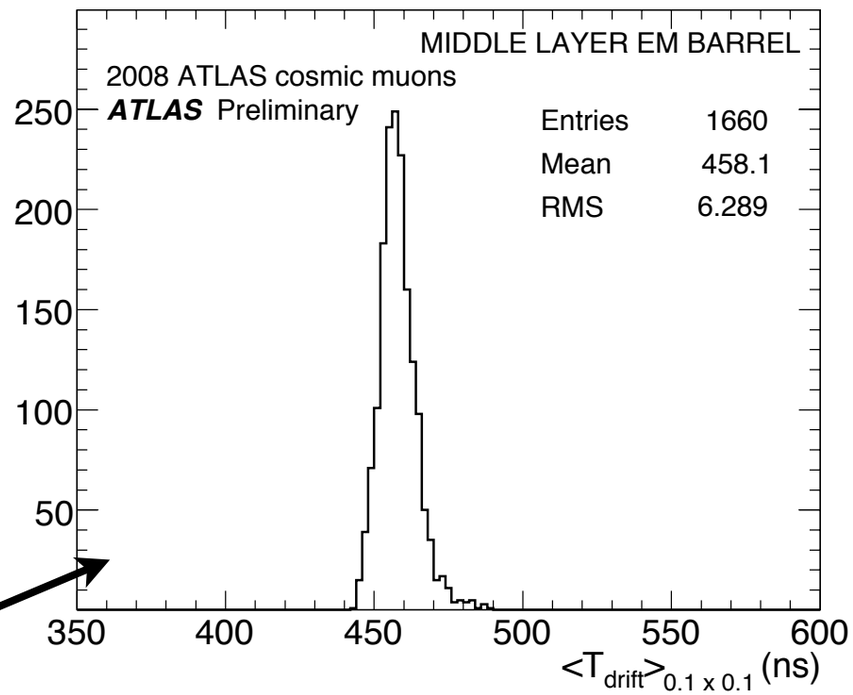
Zoom in

Calorimeters (LAr)

Pulse shape distribution from cosmic muon events. Good agreement between Data and Prediction is observed







intrinsic uniformity of the response of the barrel EM calorimeter is 0.37%

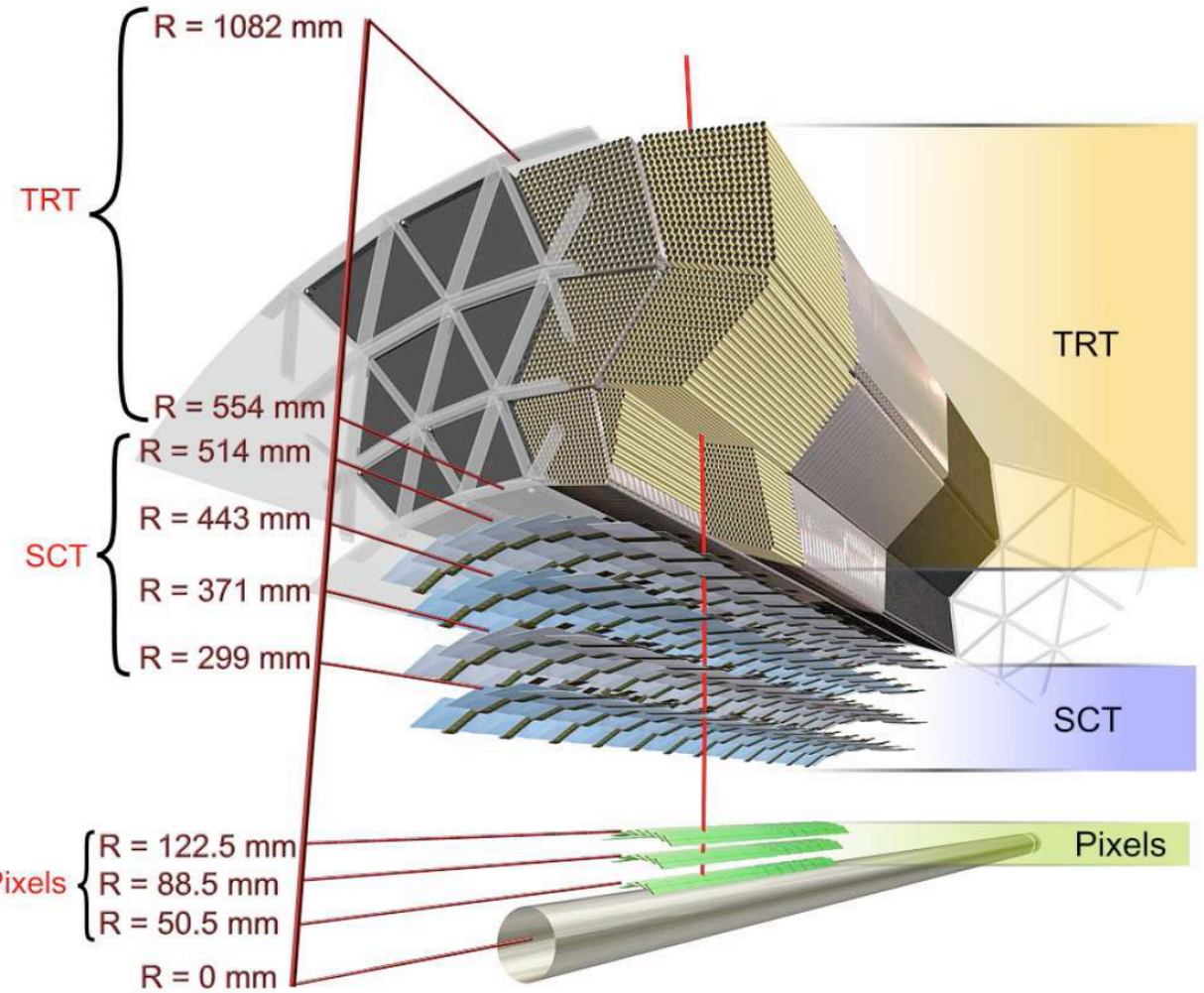
The ATLAS Inner Detector

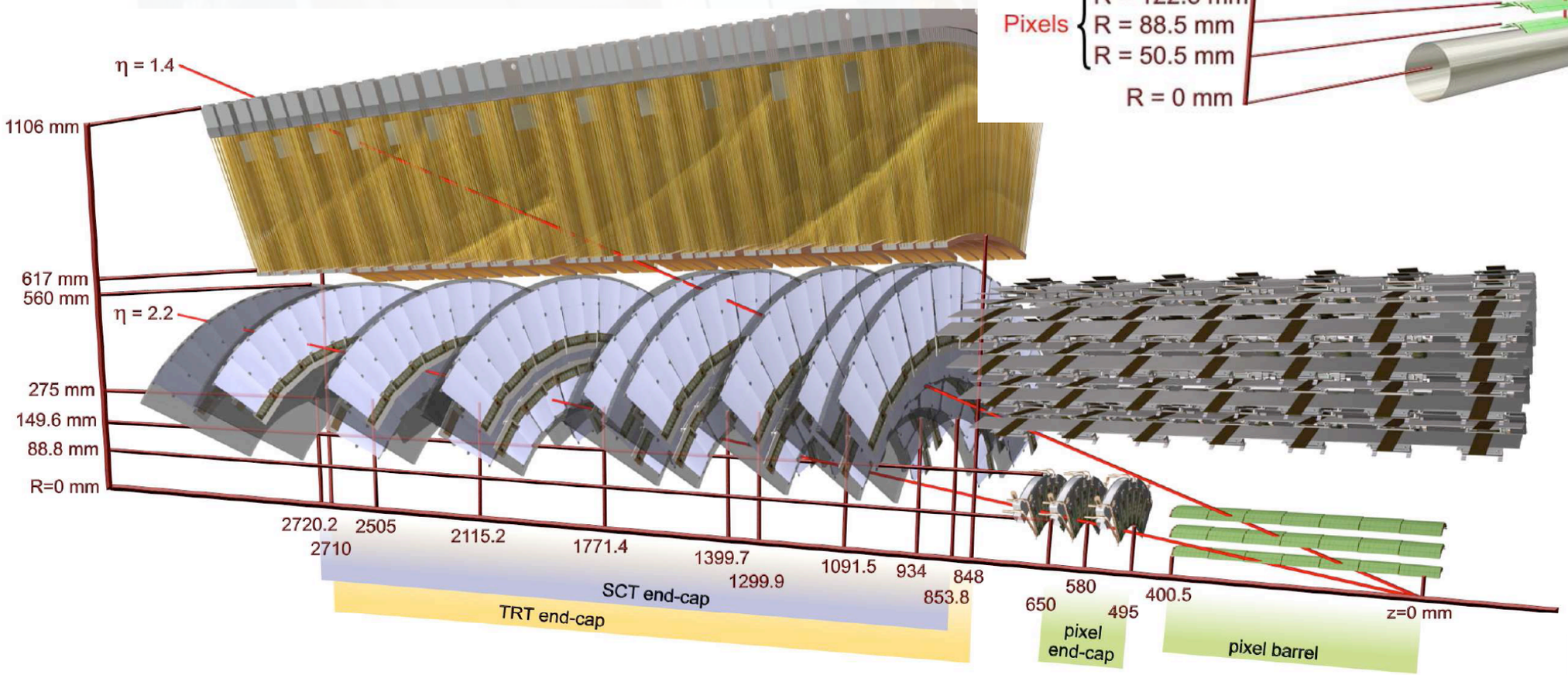
Transition Radiation Tracker (TRT)
(350k channels) with e/π separation

SemiConductor Tracker (SCT)
~6M silicon strips

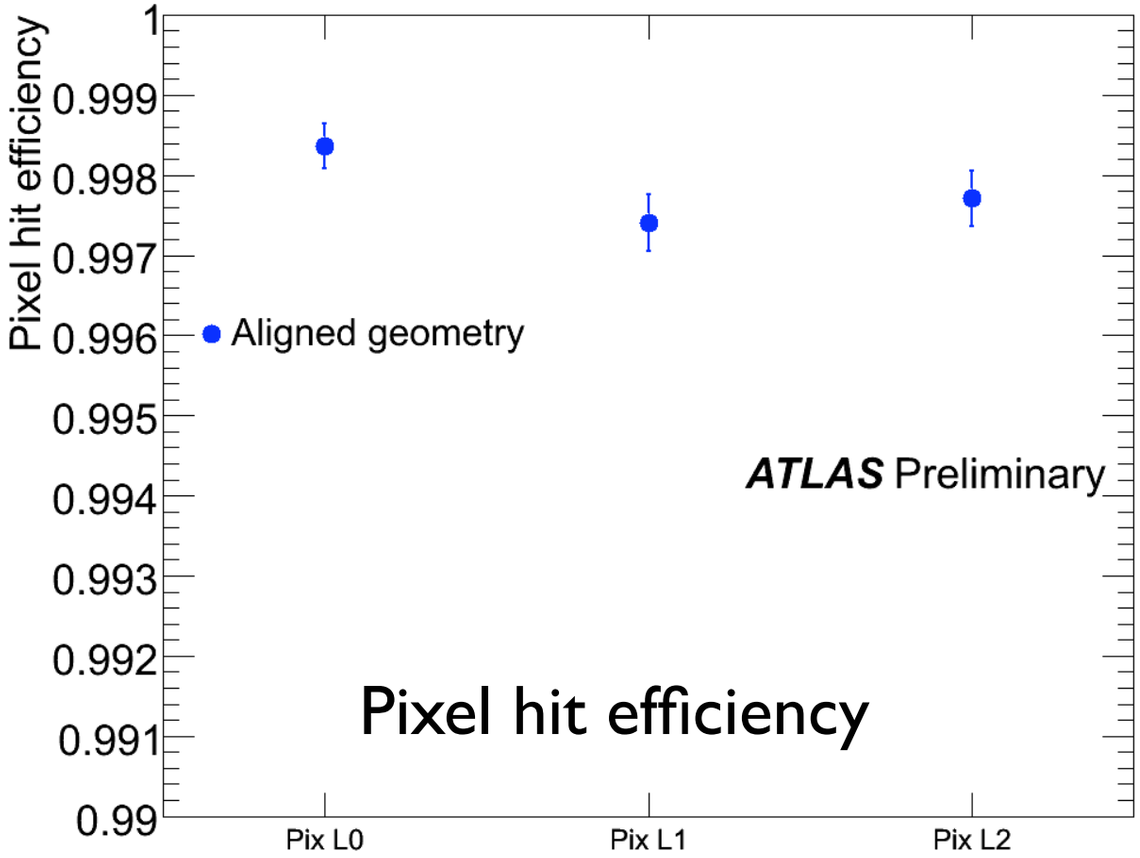
Pixels: 80M channels

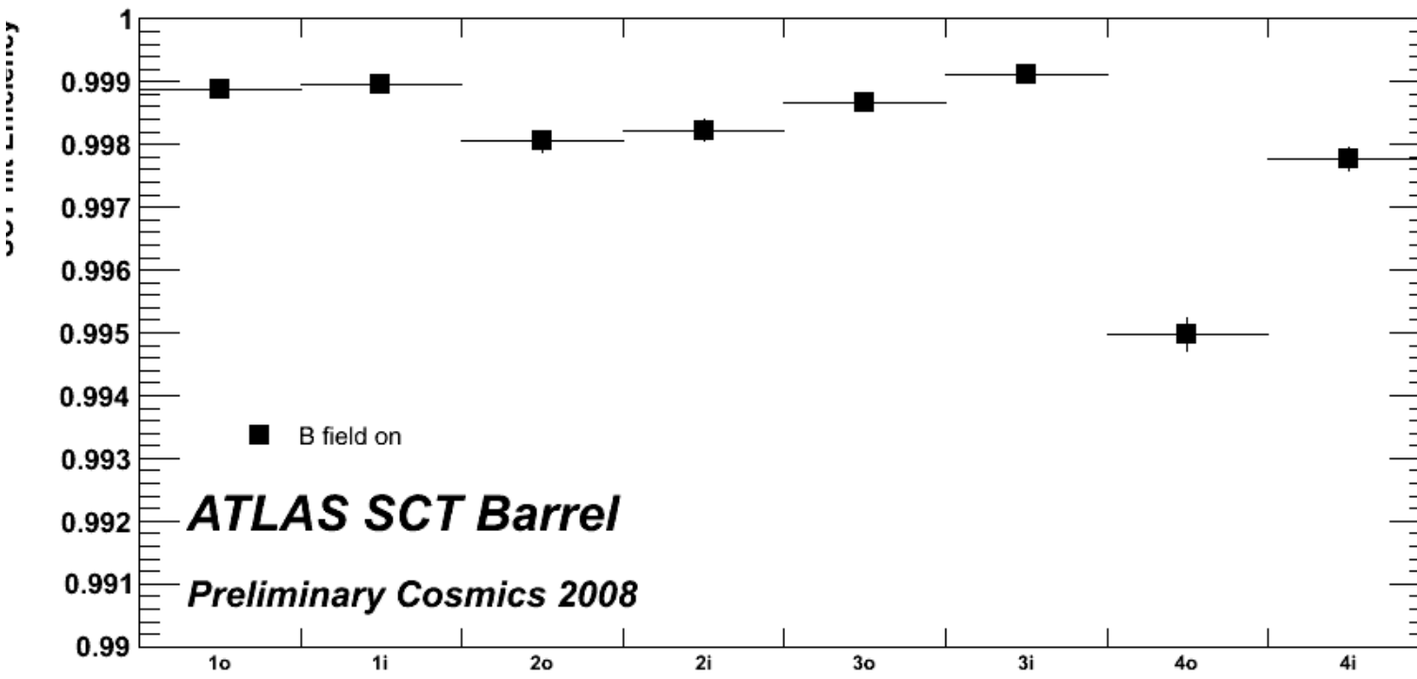
2 Tesla Solenoid
$\sigma/pT \sim 5x10^{-4}\ pT \oplus 0.01$



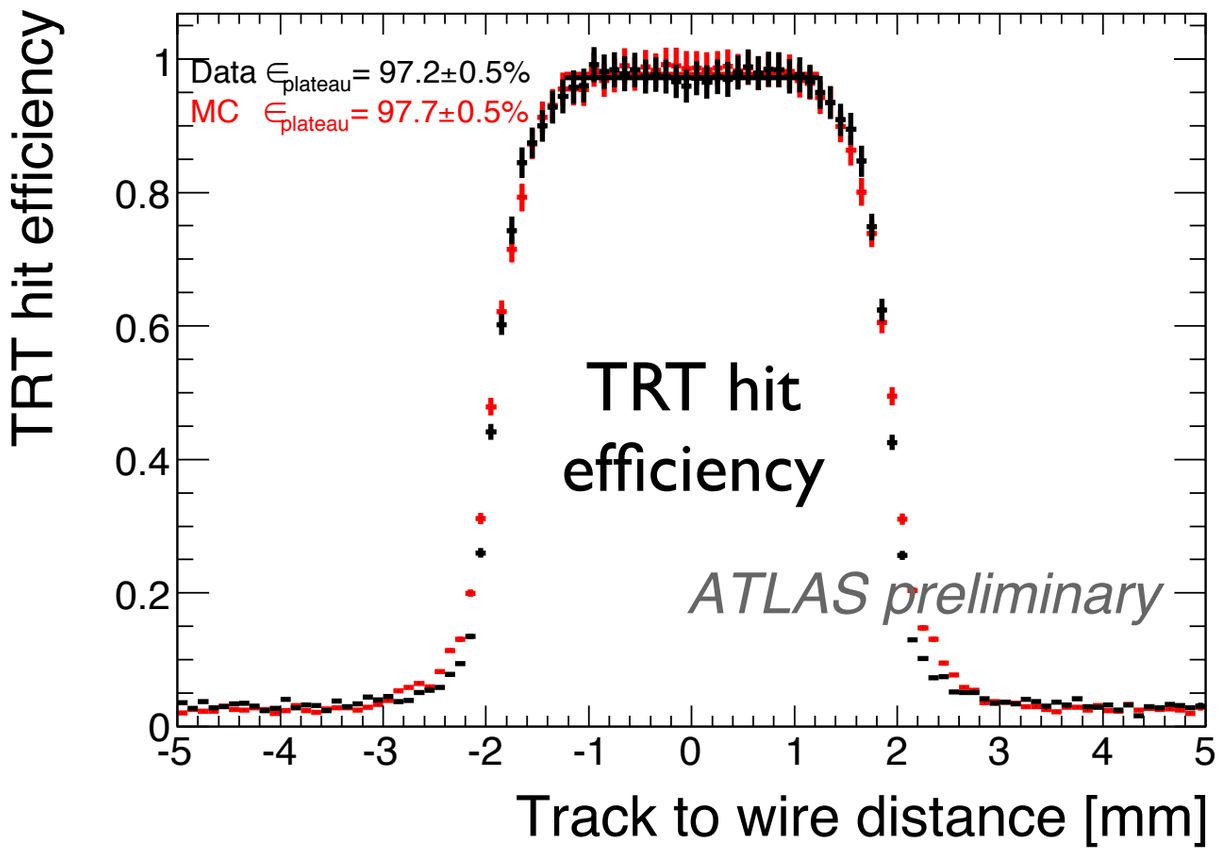


Inner Detector

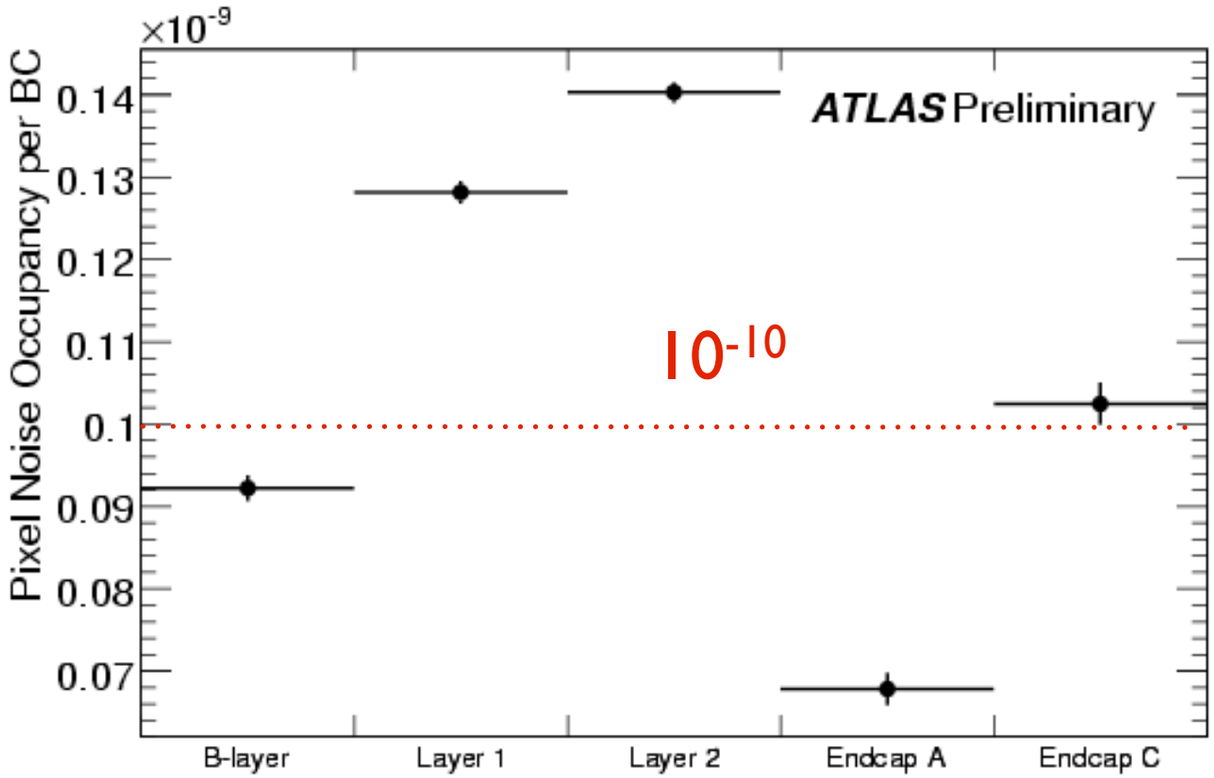


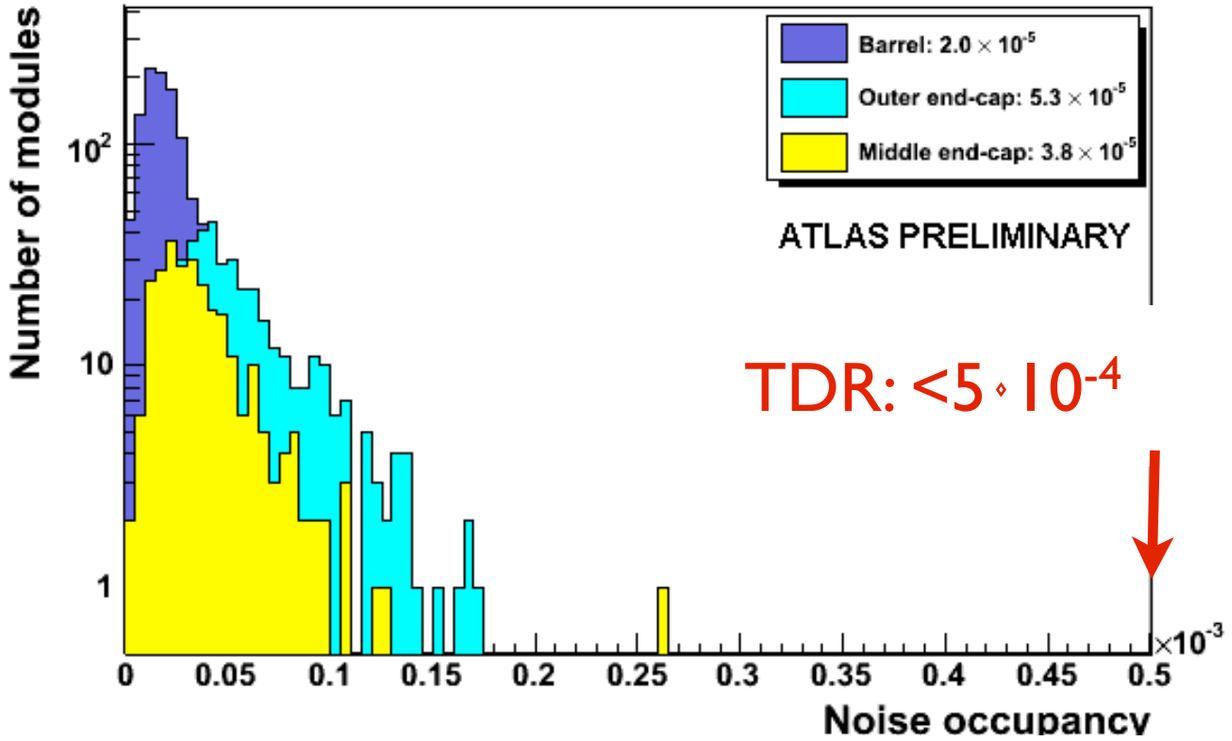


- Subdetector hit efficiency
  - >99% for the silicon based detectors
  - ~97% for the TRT, also shape in very good agreement with MC

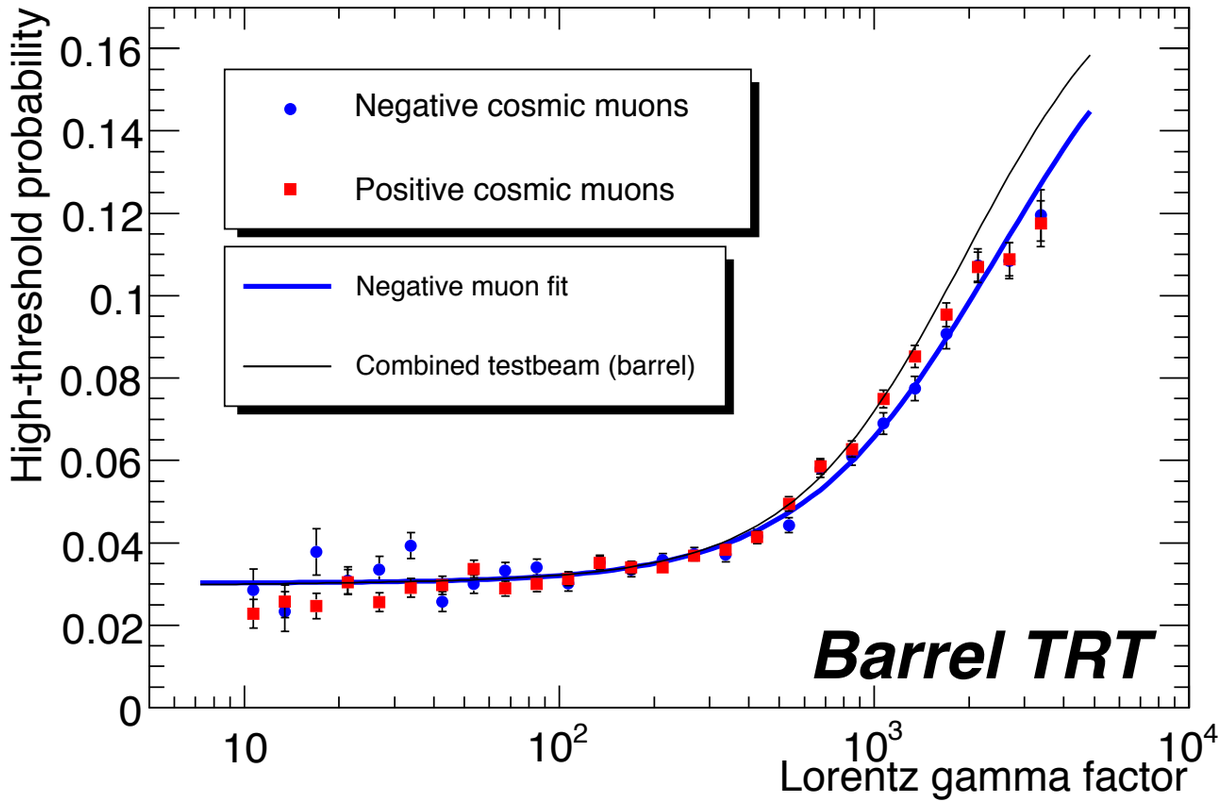


Inner Detector





- Pixel and SCT noise occupancy very low as expected
  - Less than 1 Pixel hit per BC from noise!
- Transition radiation onset clearly visible

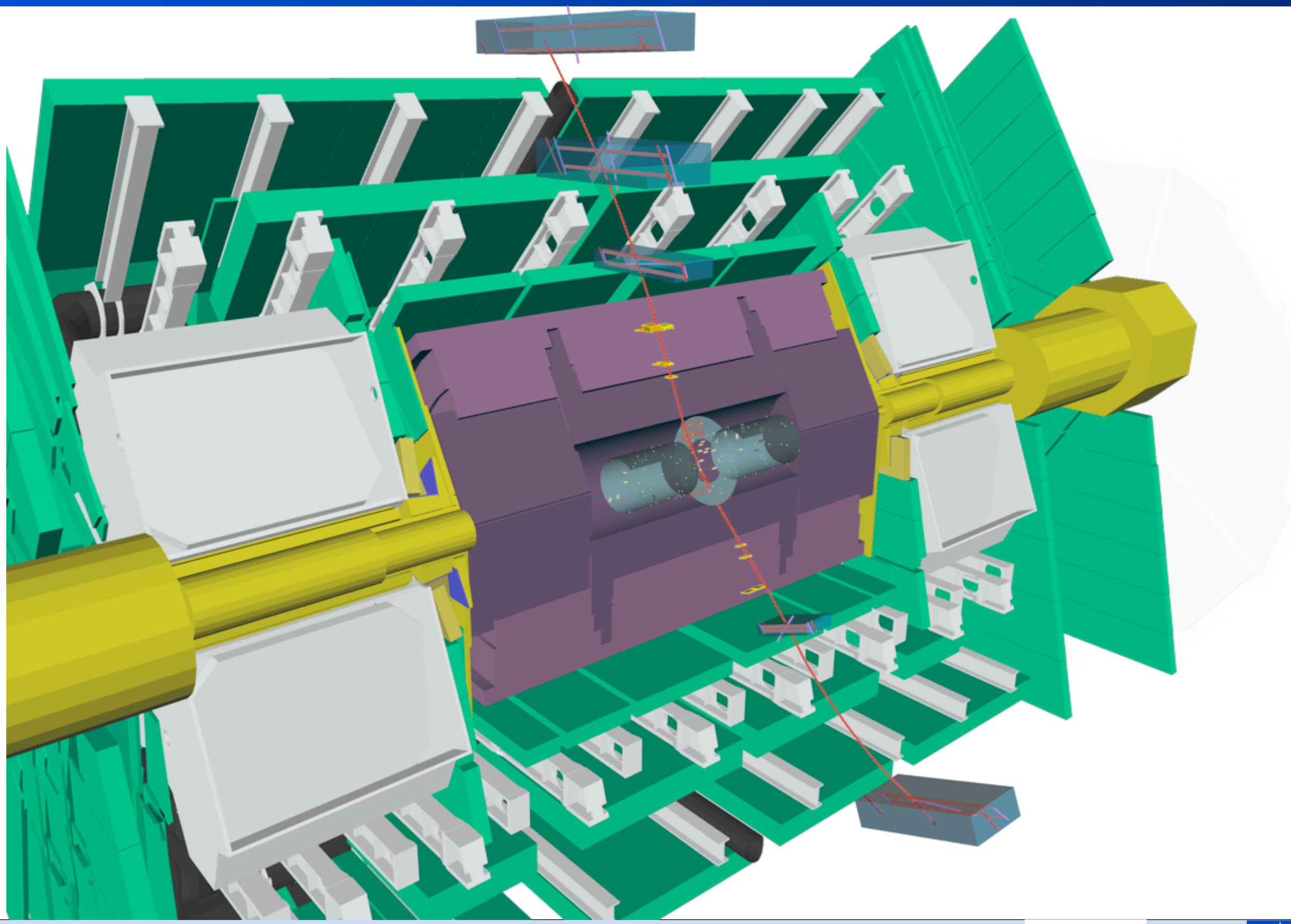


ATLAS Detector status (start of LHC)

Subdetector	Number of channels	Approximate Operational Fraction
Pixels	80 M	98.0 %
Silicon Strips (SCT)	6.3 M	99.3 %
Transition Radiation Tracker (TRT)	350 k	98.2 %
LAr EM Calorimeter	170 k	99.1 %
Tile Calorimeter	9800	99.5 %
Hadronic endcap LAr calorimeter	5600	99.5 %
Forward LAr calorimeter	3500	100 %
Muon Drift Tubes (MDt)	350 k	99.3 %
Cathode Strip Chambers (CSC)	31 k	98.4 %
RPC Barrel Muon Trigger	370 k	>97 %
TGC Endcap Muon Trigger	320 k	99.8 %

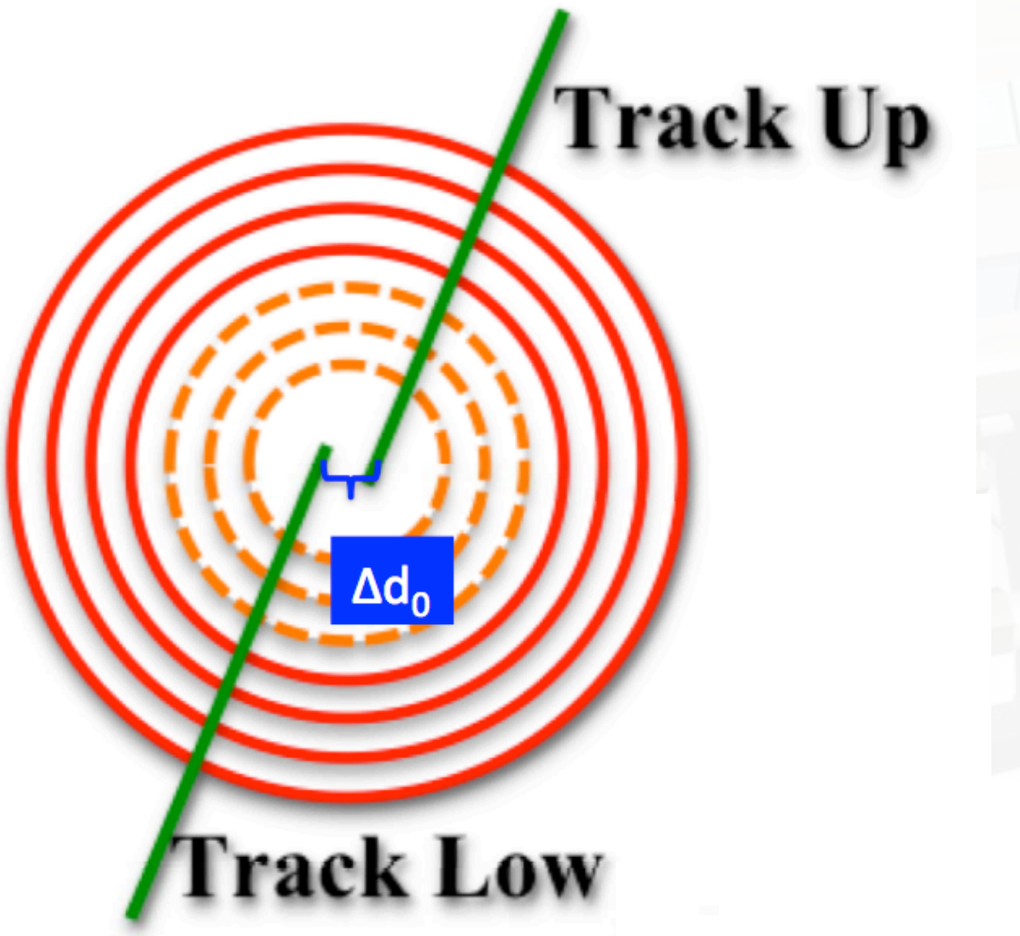
Data taking efficiency (from June cosmic run, averaged over 6h-14h stores): ~83%

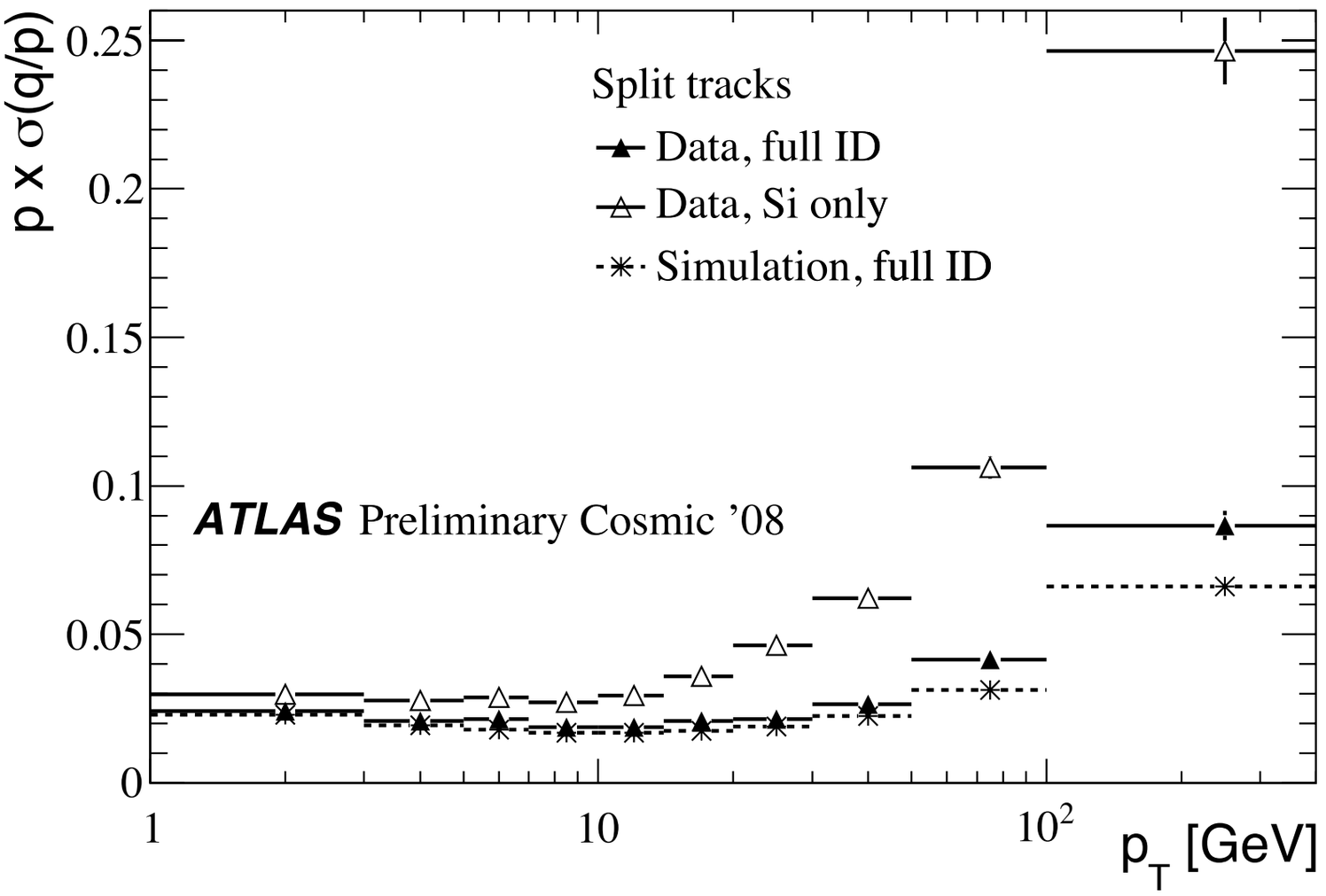
Cosmic events as a test for combined reconstruction



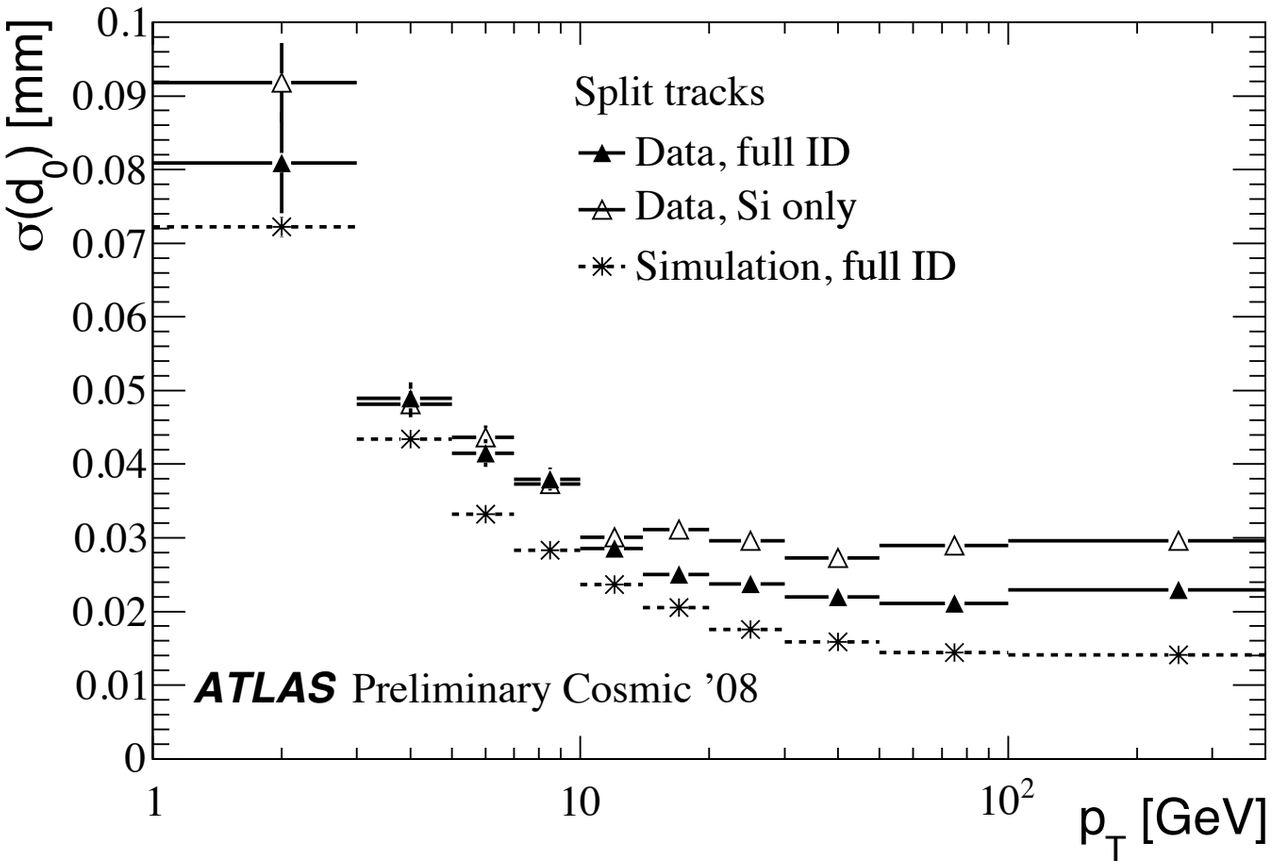
Performance of Inner Detector track reconstruction

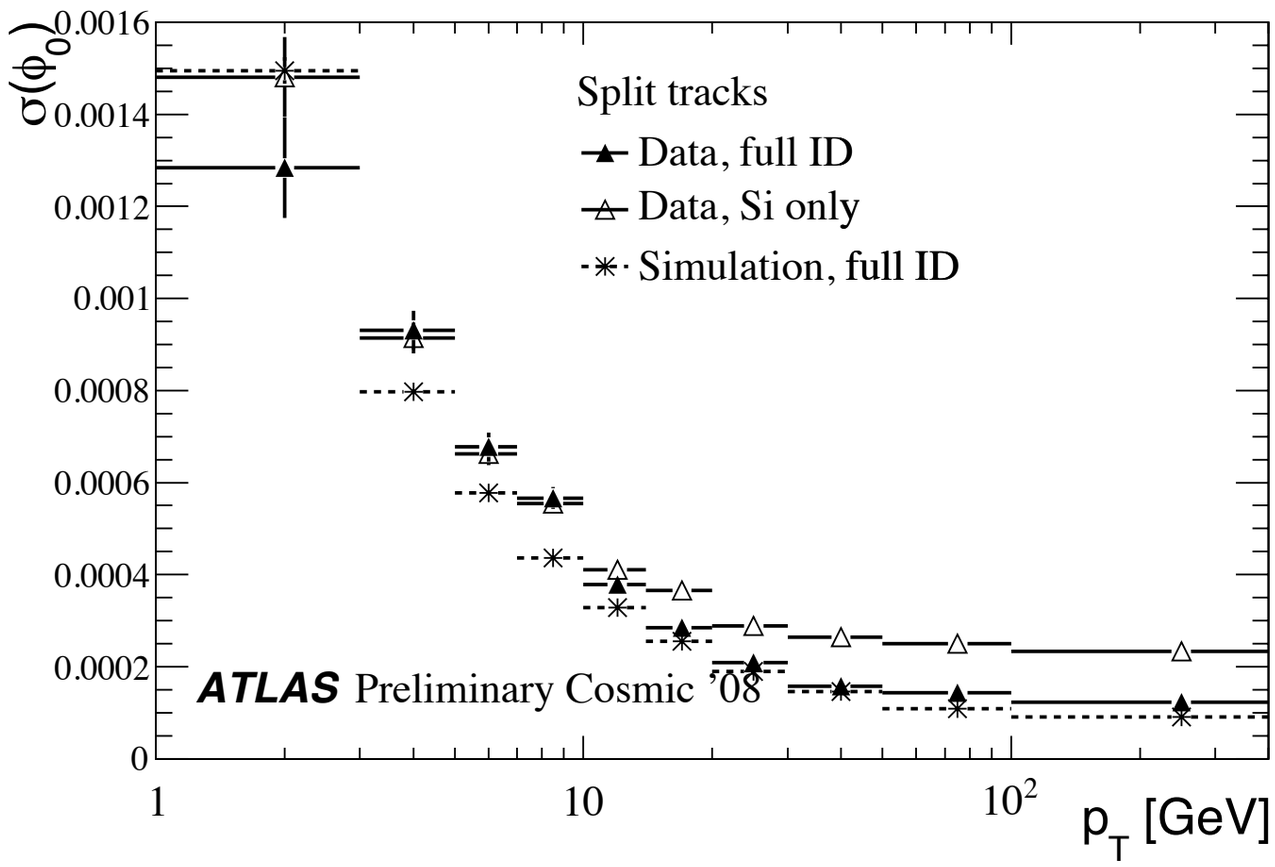
- Cosmic tracks cross both the upper and the lower hemisphere of the ID
  - Tracks split in the center and refitted separately allow to measure the track parameter resolution and bias directly in data
- With the current alignment already very close to ideal detector performance



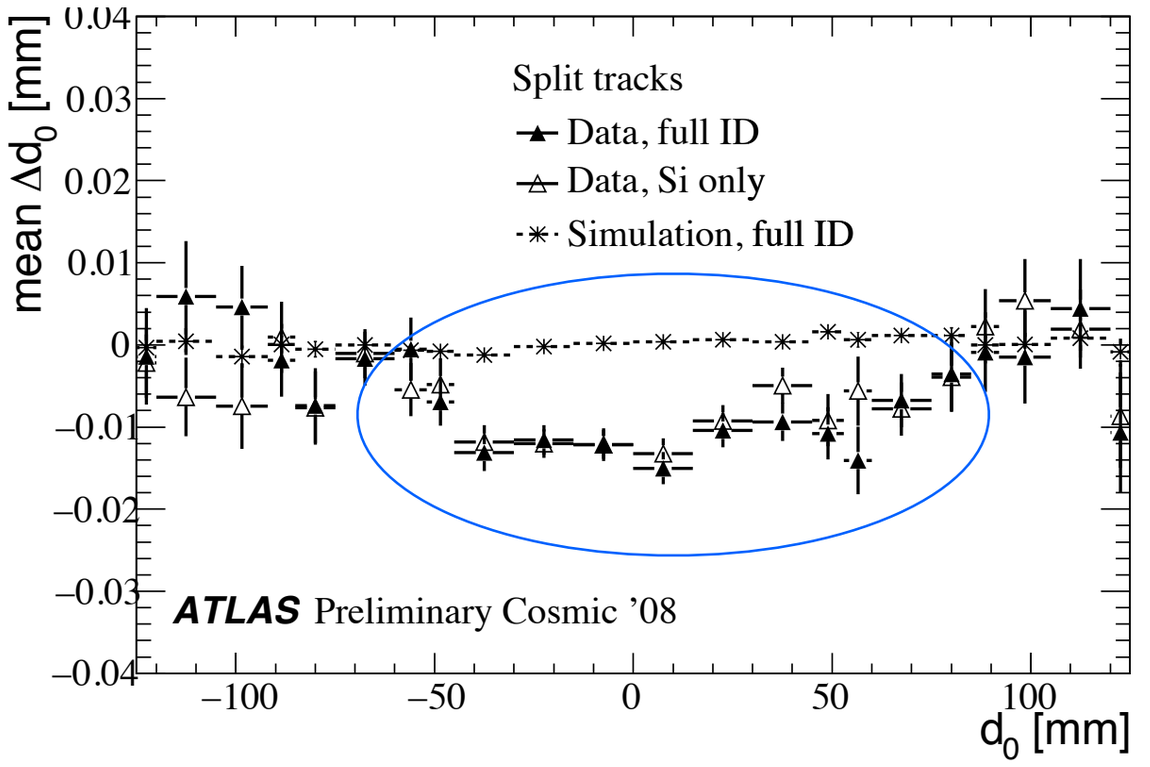


Performance of Inner Detector track reconstruction (II)

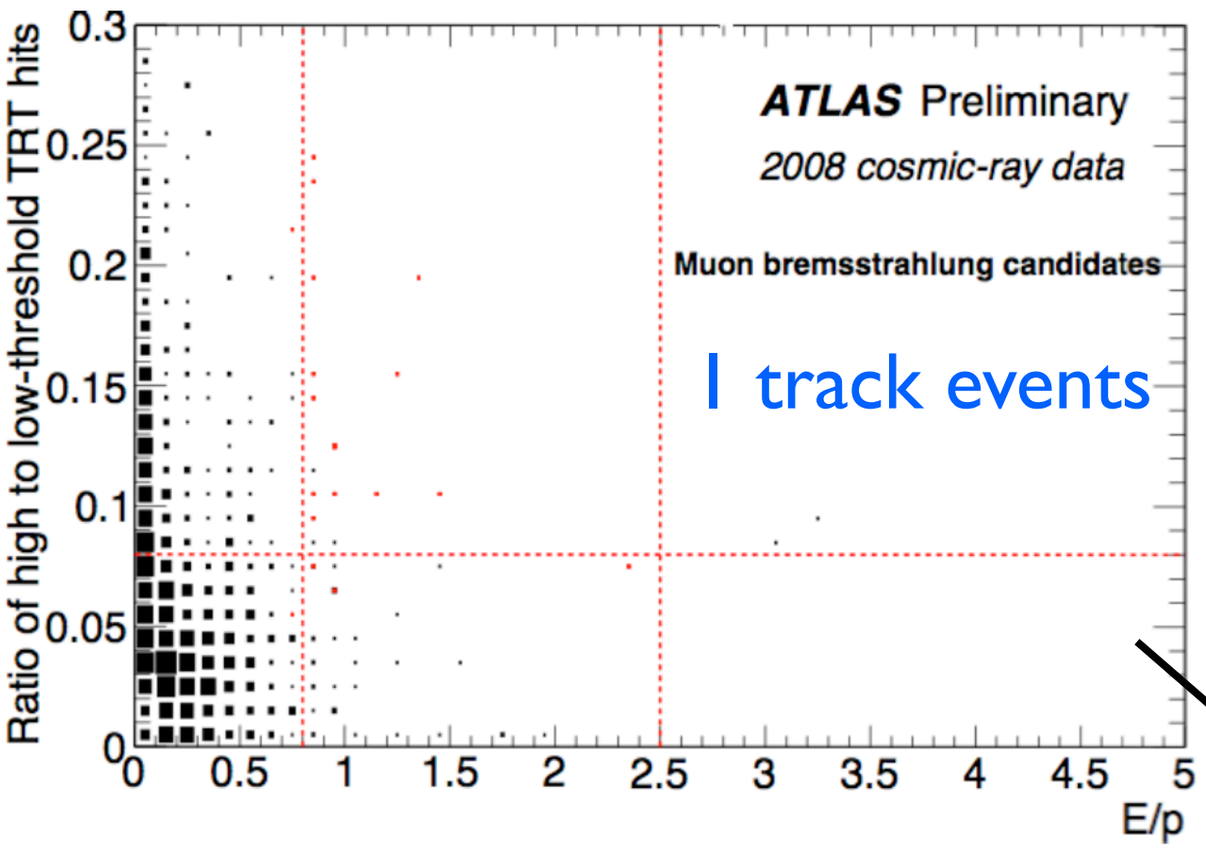


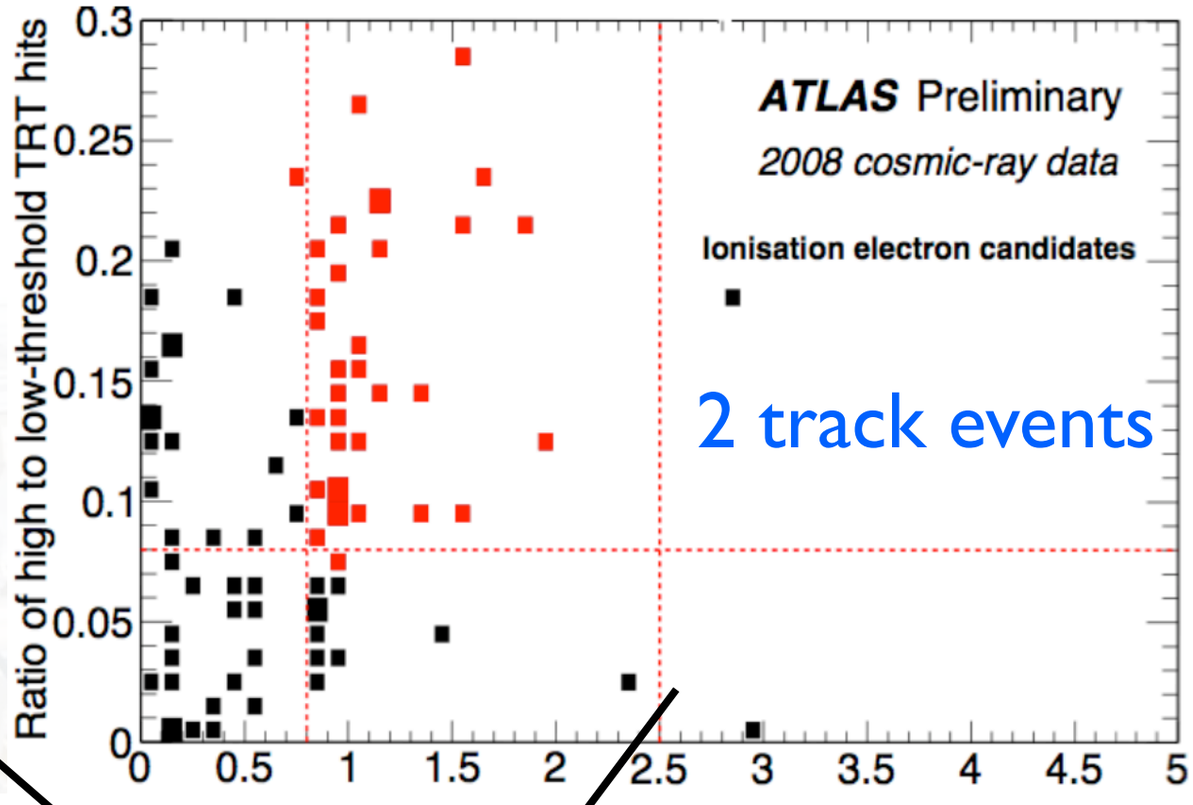


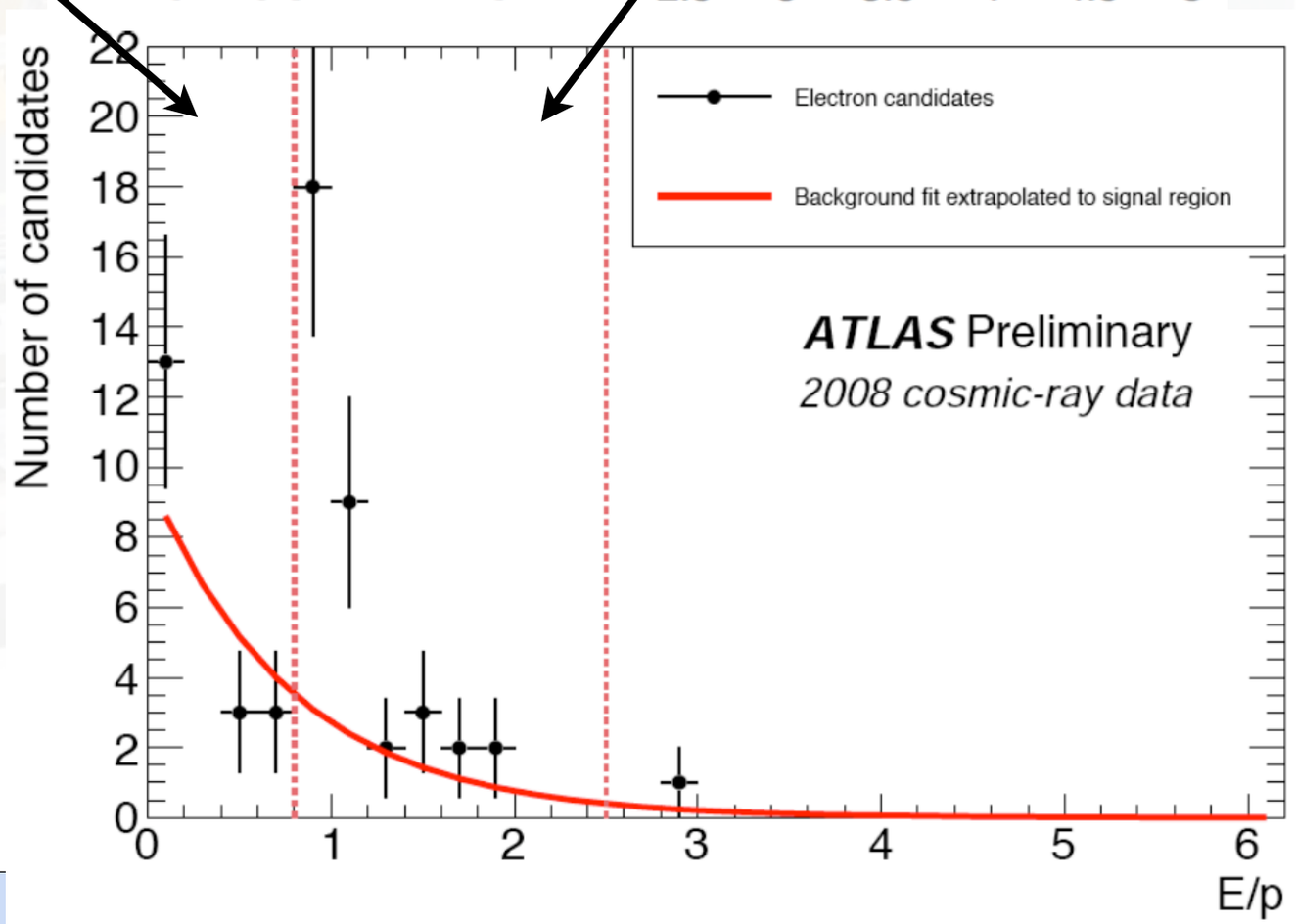
- Some small biases are seen and are under study in the alignment group
  - Need also collision data to remove these residual biases



First electrons seen in ATLAS!

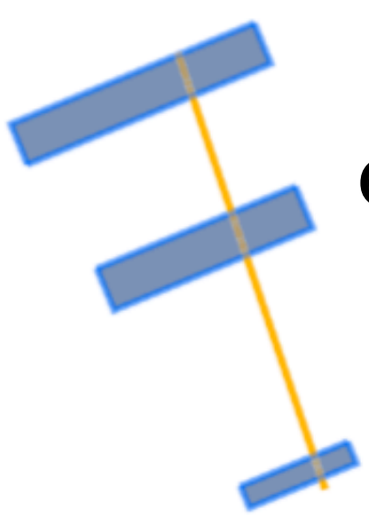




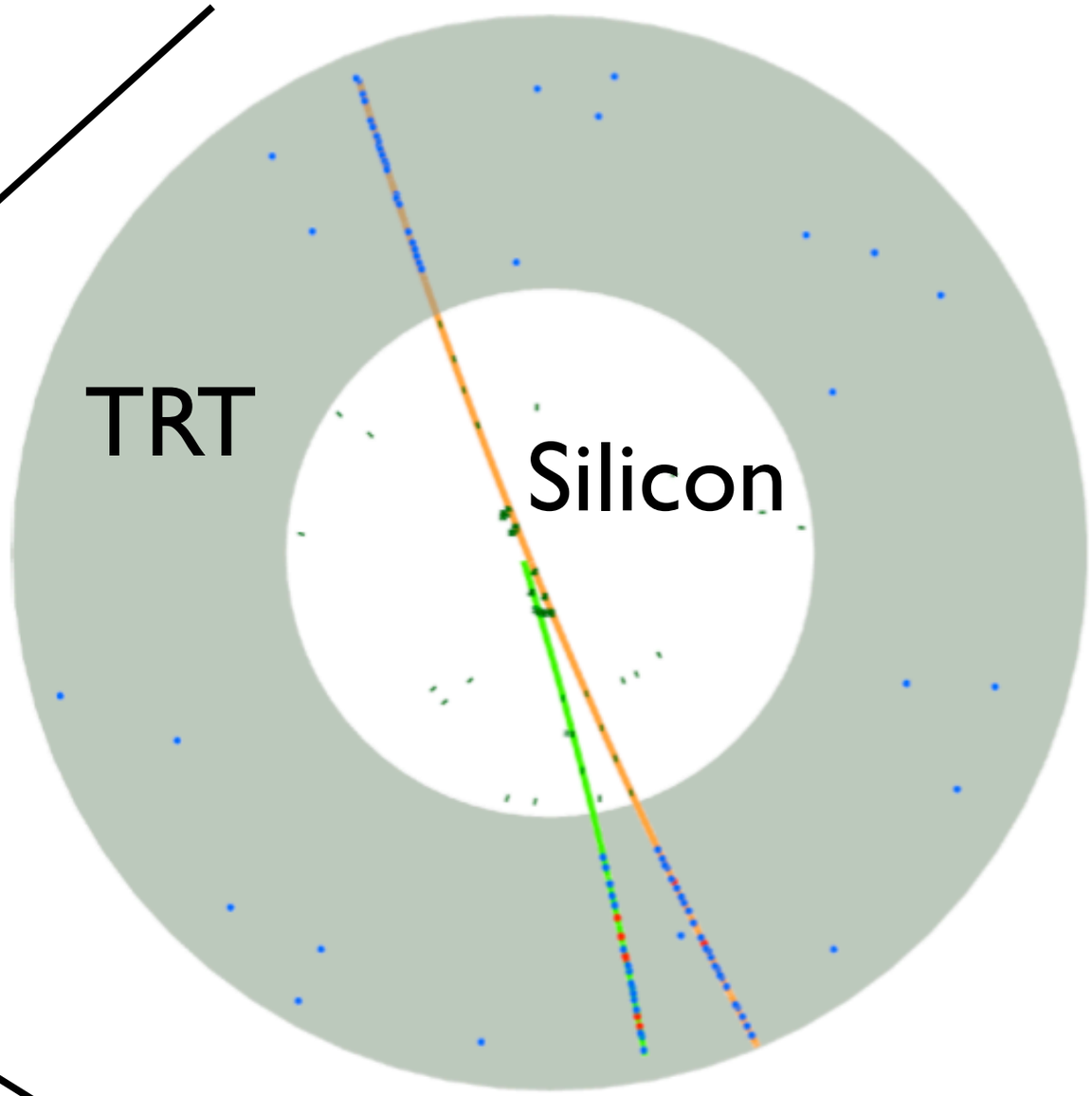


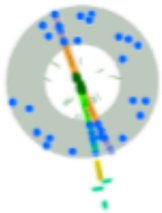
- Electrons in cosmic events are produced via ionisation
- Background due to muon bremsstrahlung
- Electrons above ~3 GeV can be identified by standard ATLAS electron selection

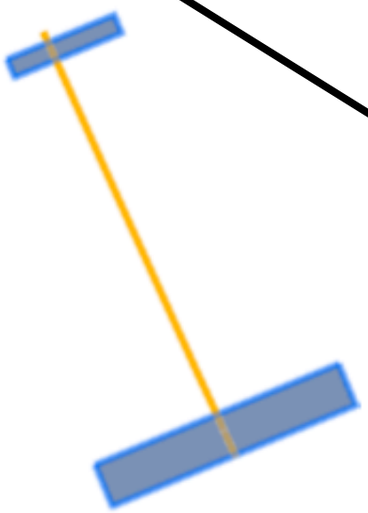
Event display of one of the electron candidates



Muon chambers



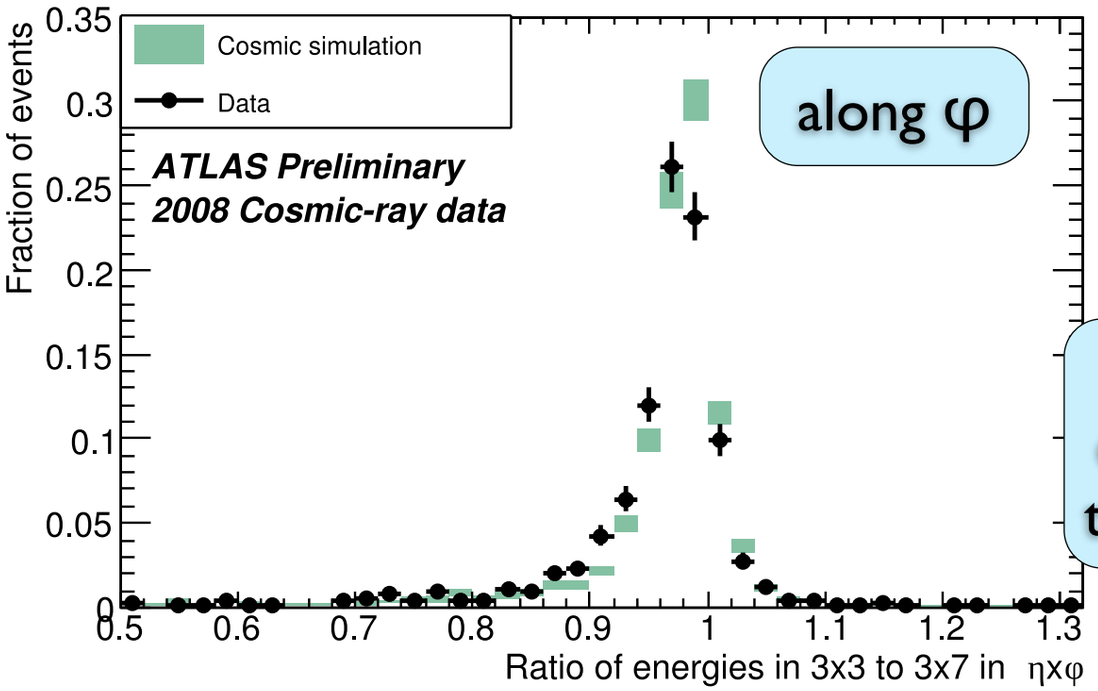




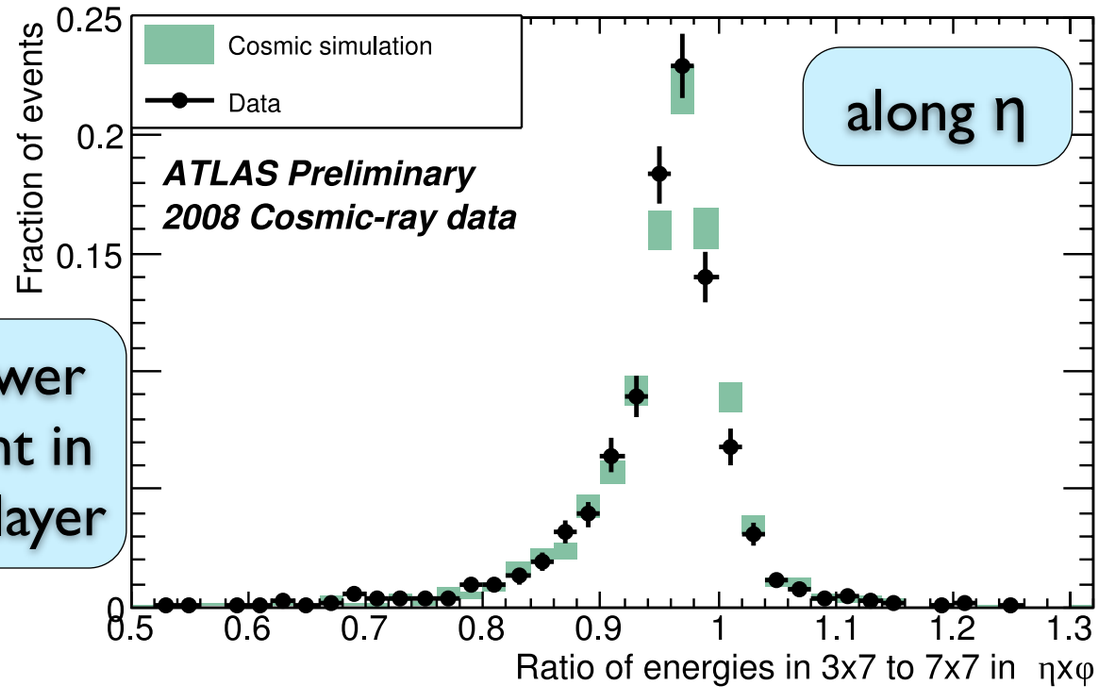
Muon chambers

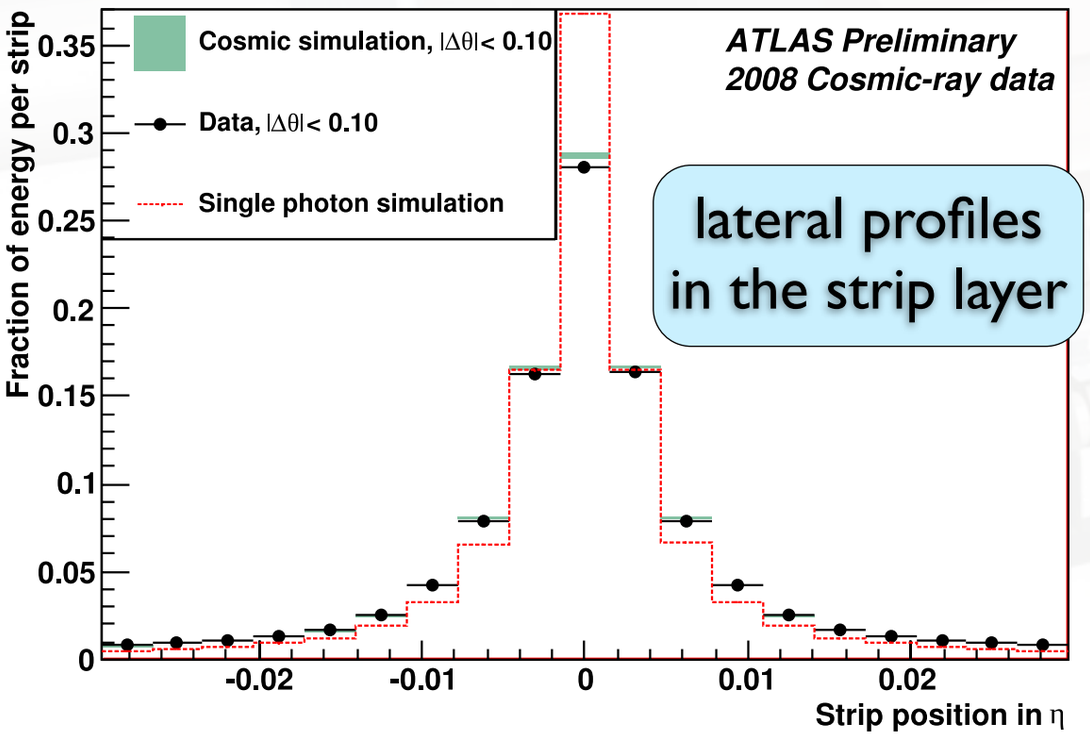
Calorimeter Cluster/Cells

Photon identification



lateral shower containment in the middle layer



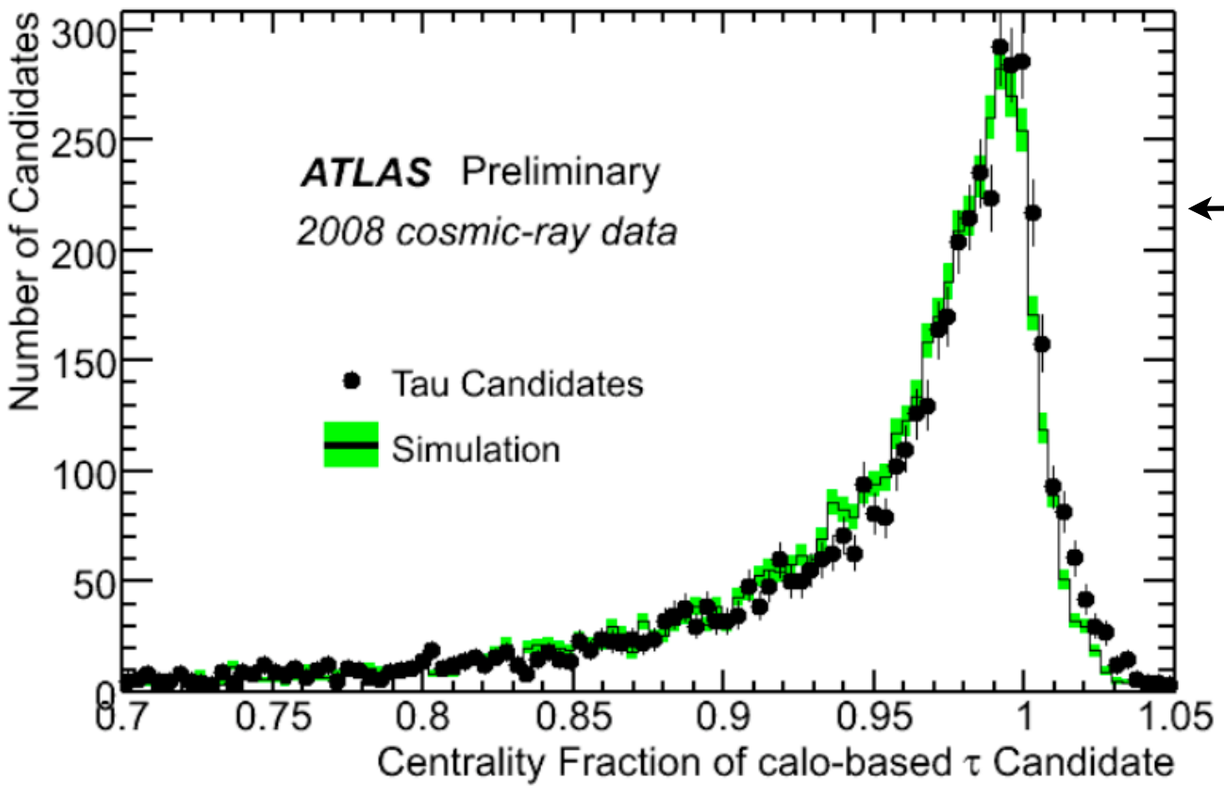


lateral profiles in the strip layer

- Shower shape variables are a key component of photon and electron identification
  - Good agreement seen between cosmic ray data and simulation
  - Robust variables for electron/photon identification with early data

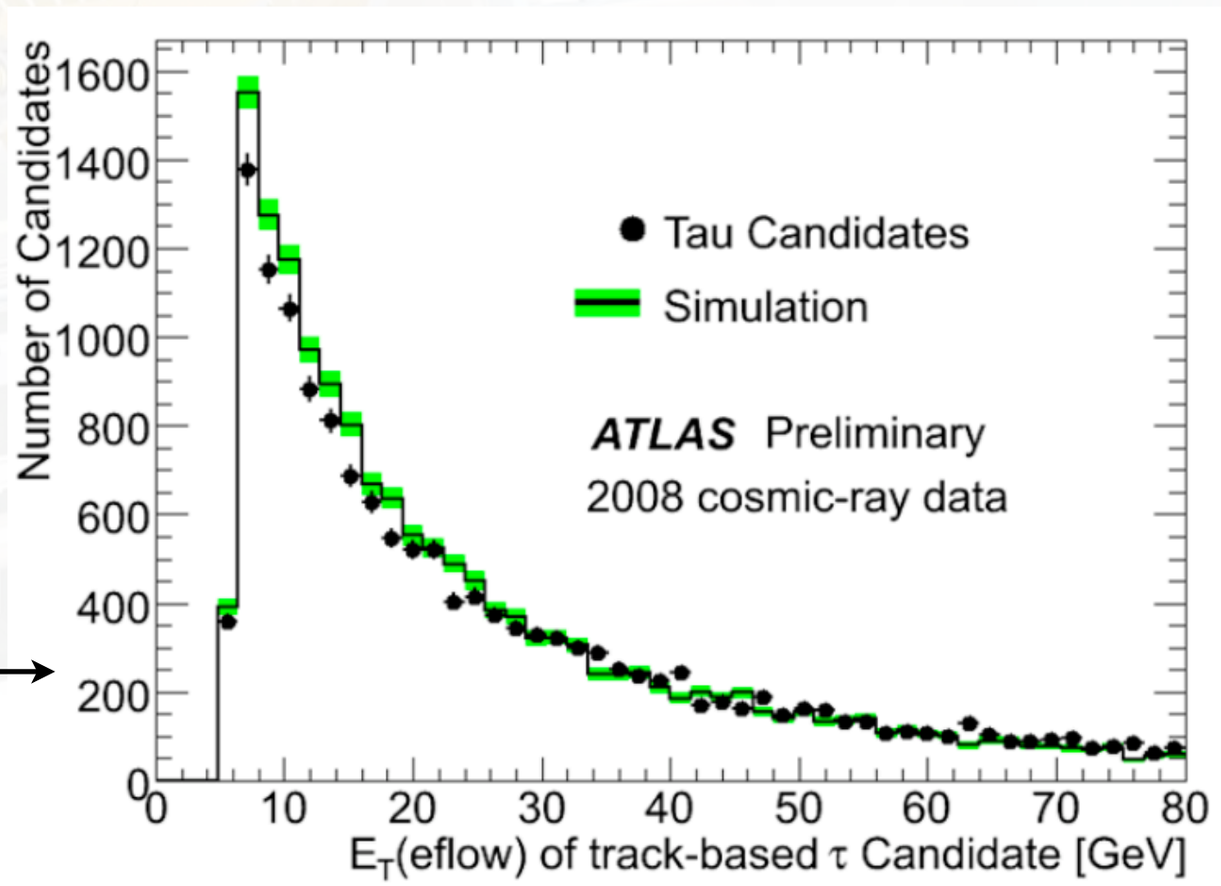
Tau identification

- Obviously no real tau leptons in cosmic events, however good opportunity to check Data/MC agreement of tau identification variables

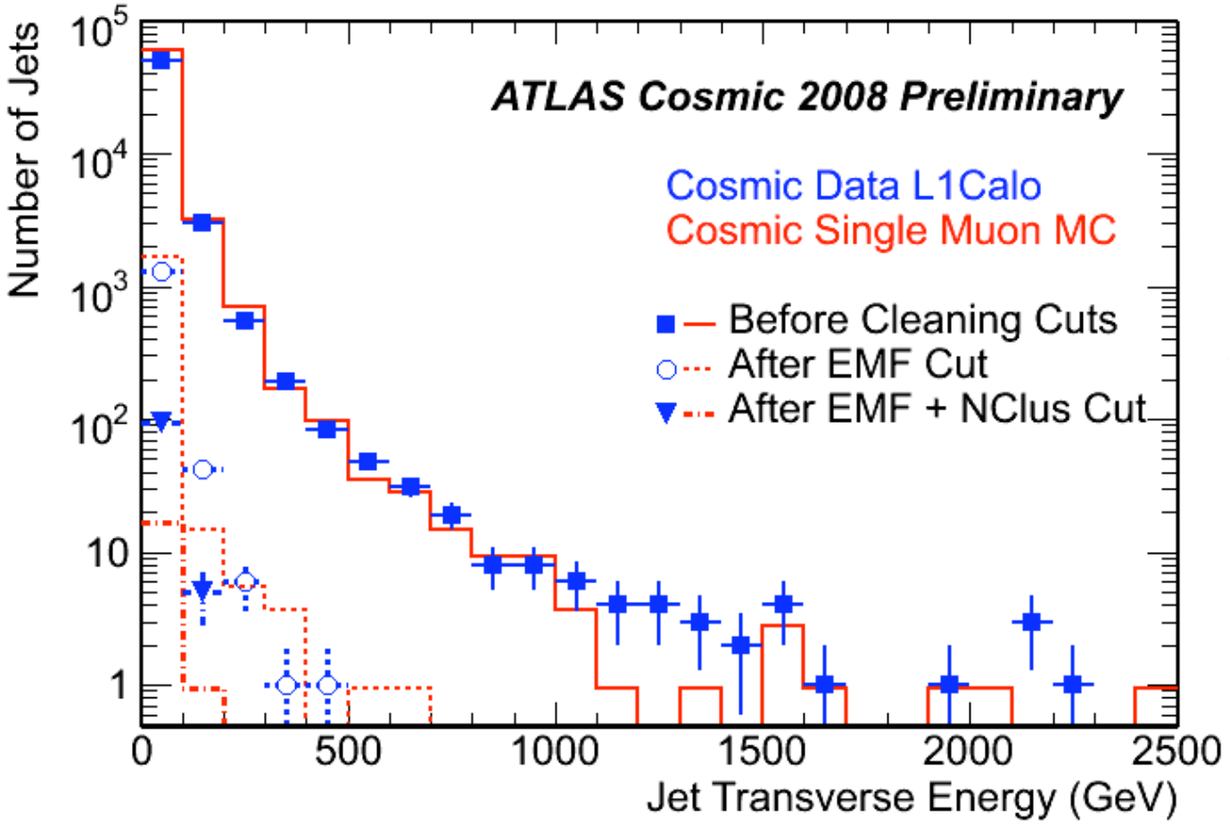


Centrality fraction (ratio of transverse energy in a R=0.1 cone over transverse energy in a cone of R=0.4)

Transverse energy of the tau candidate calculated via an energy flow algorithm

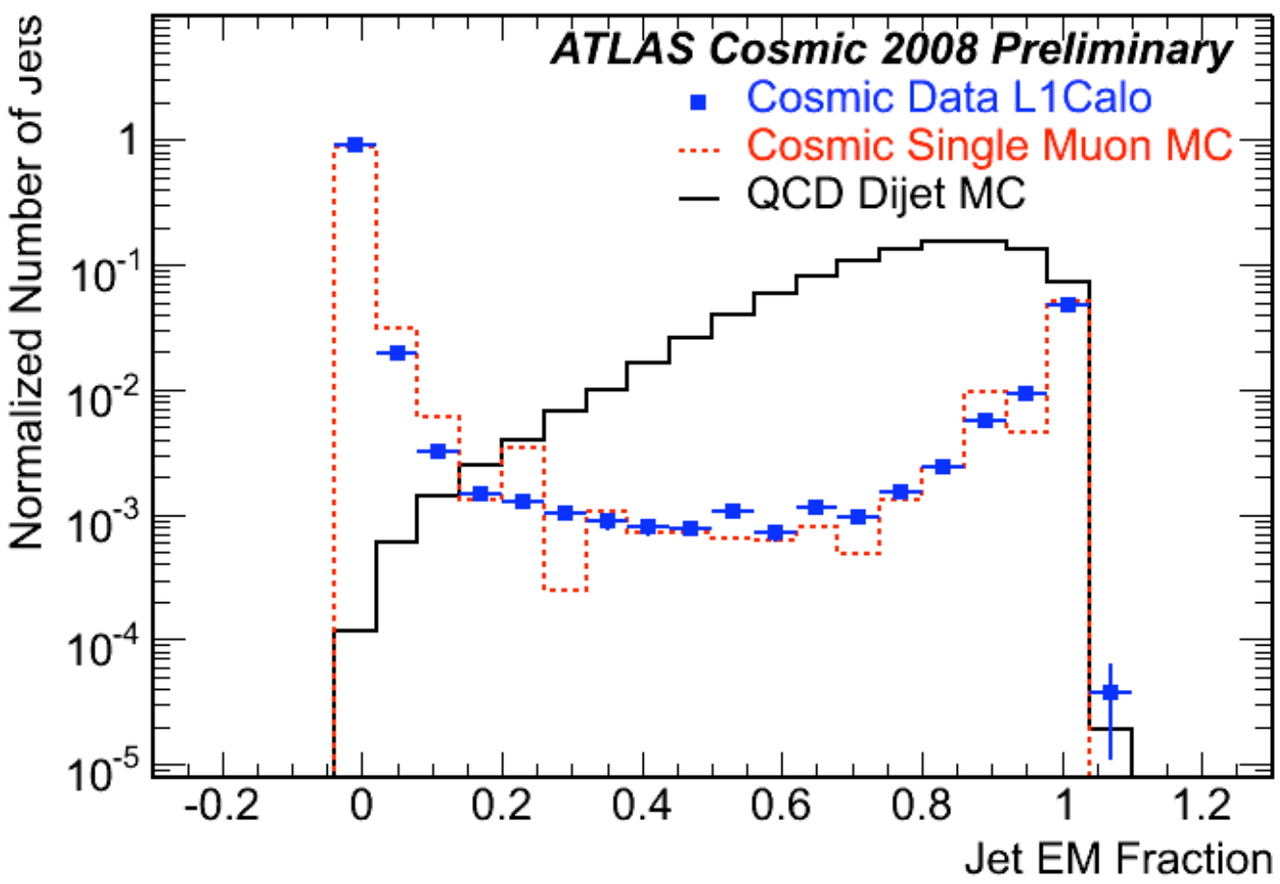


Jet studies on cosmic ray data

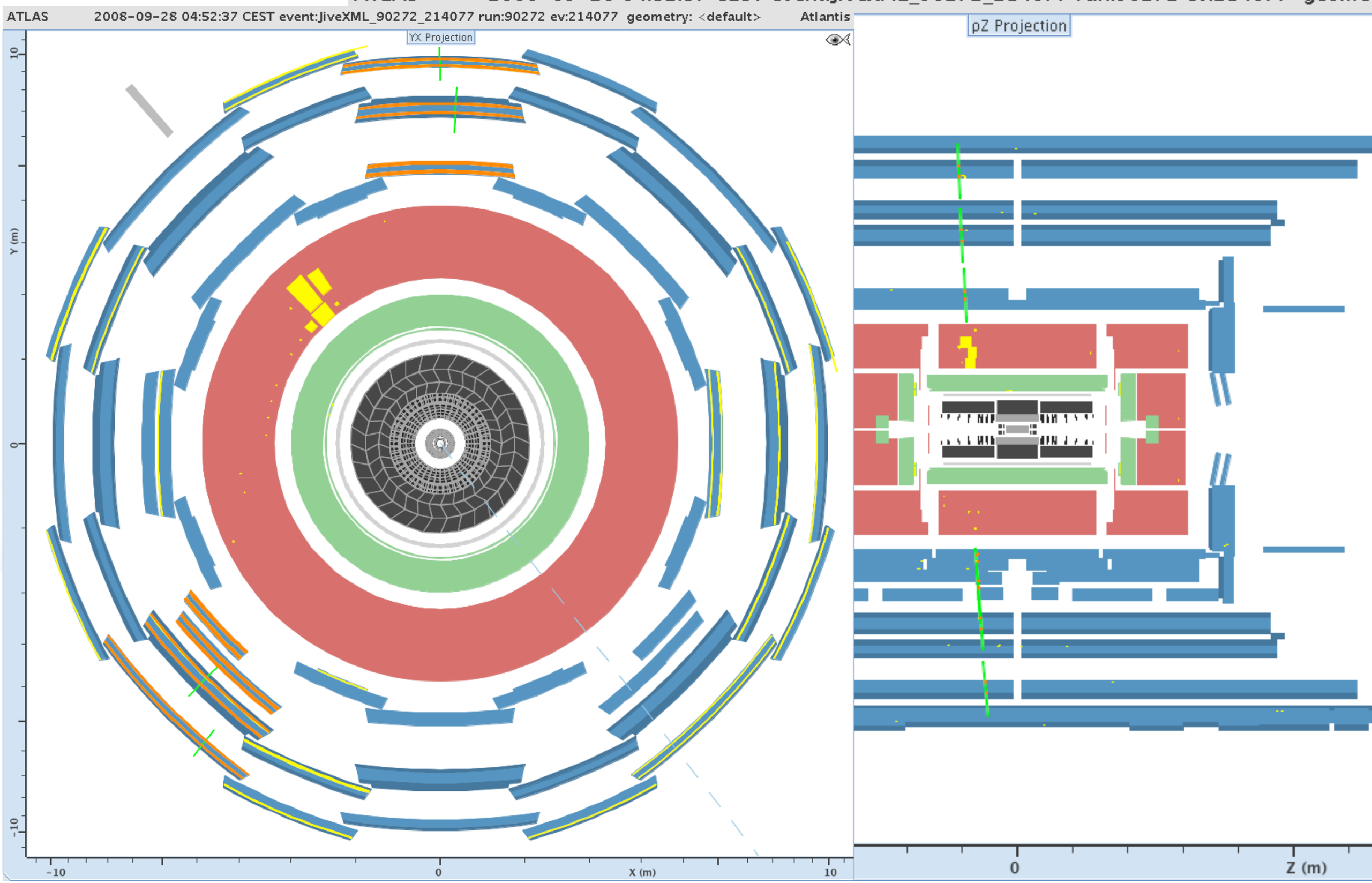


Jet transverse energy distribution for events triggered by the calorimeter trigger in comparison with cosmic MC

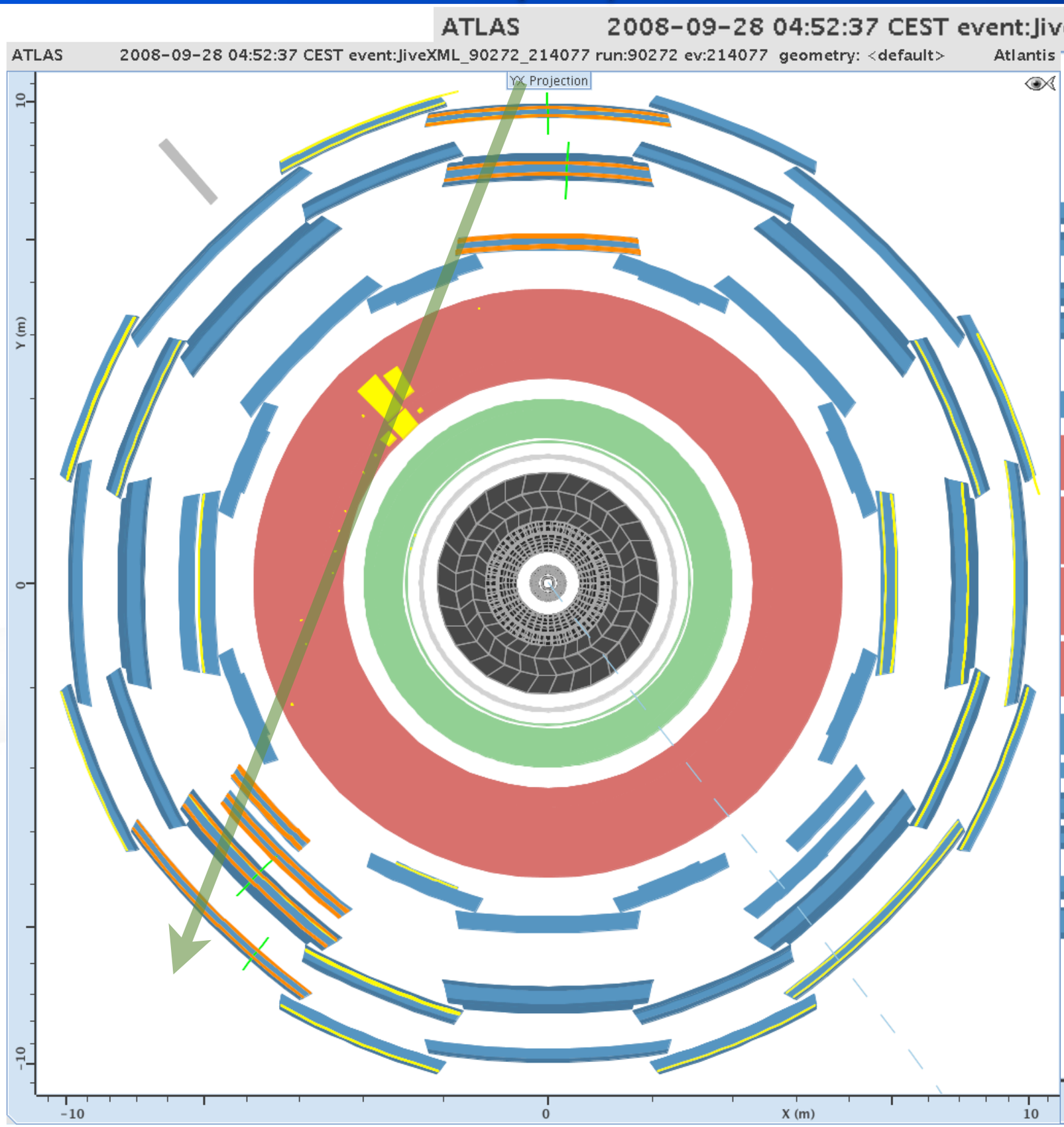
A comparison between the EM fraction of jets from cosmic events and from simulated QCD events shows that cuts on the EM fraction can be used to reject jets from cosmic events

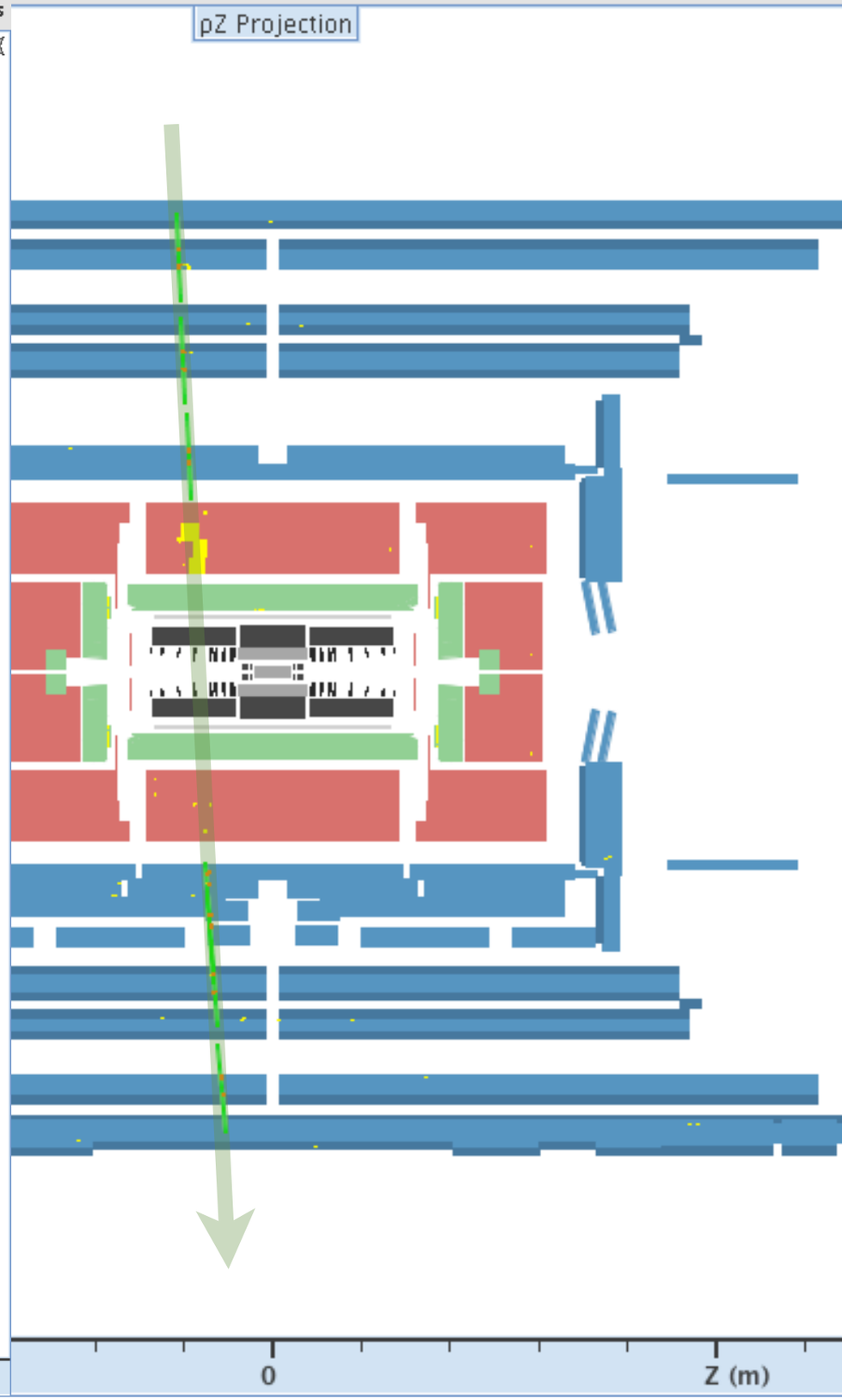


Event display of an event with a 1 TeV jet



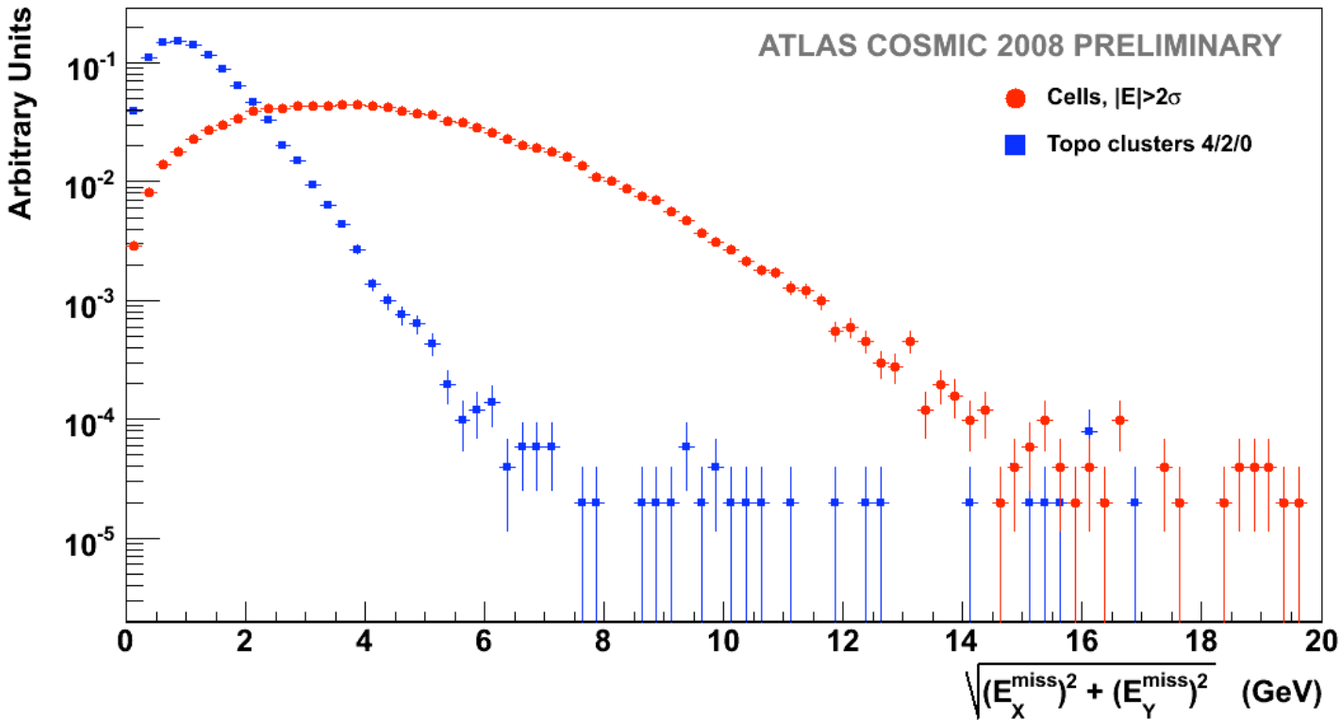
Event display of an event with a 1 TeV jet

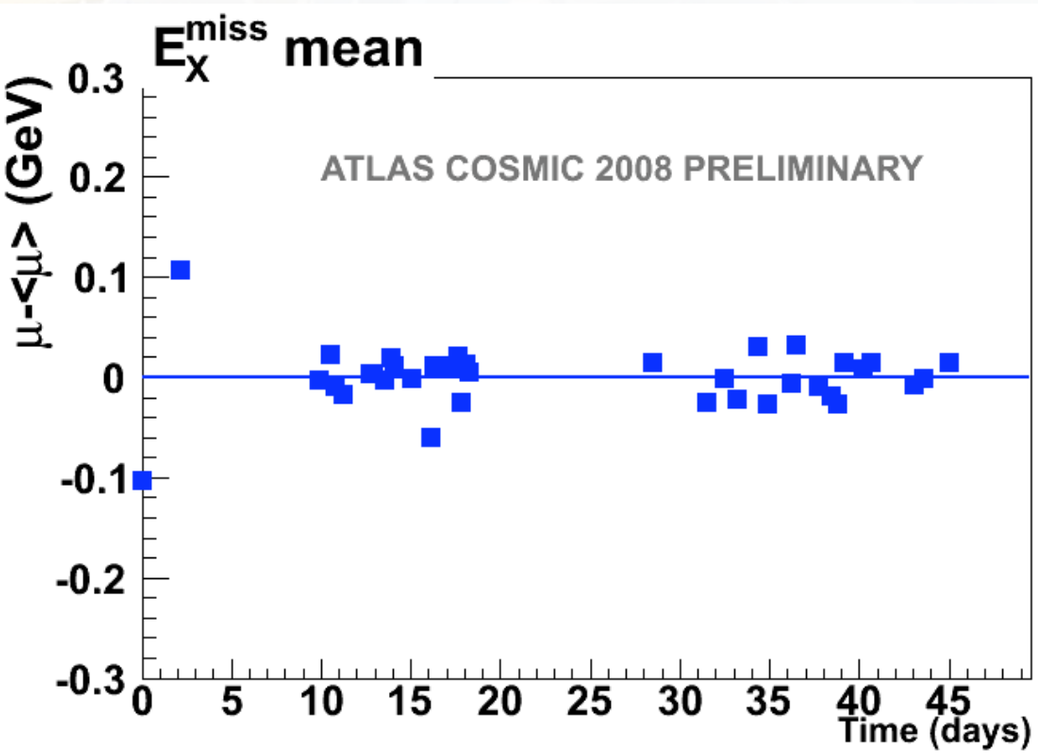




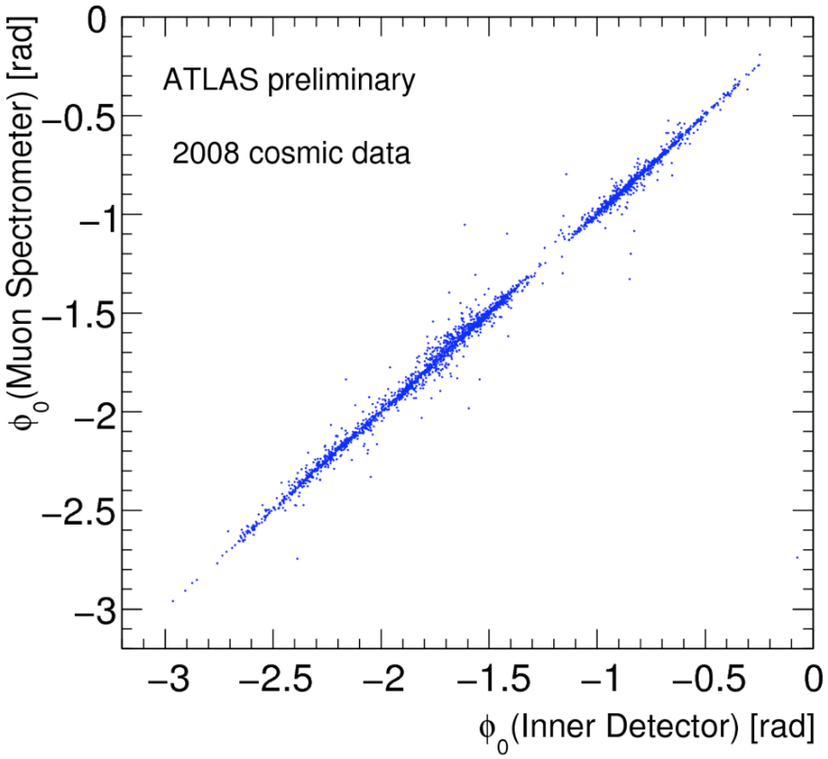
Missing energy in random triggered events

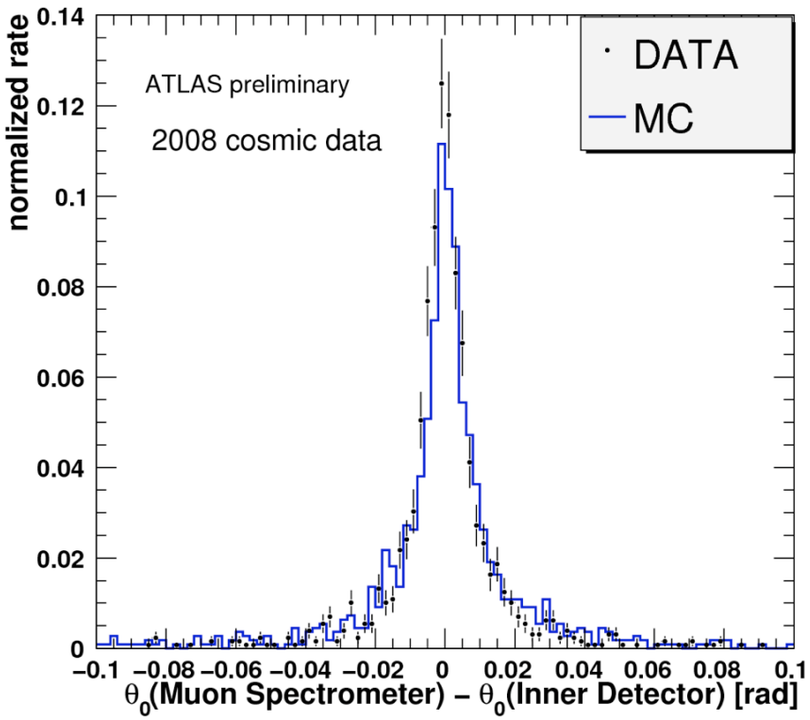
- Random triggered events allow to study the missing energy behaviour due to electronic noise
- Improvements in the noise suppression due to the topo cluster approach are clearly visible over the simple cell based approach
- Stability of the missing energy has also been verified over the full running period in september and october 2008

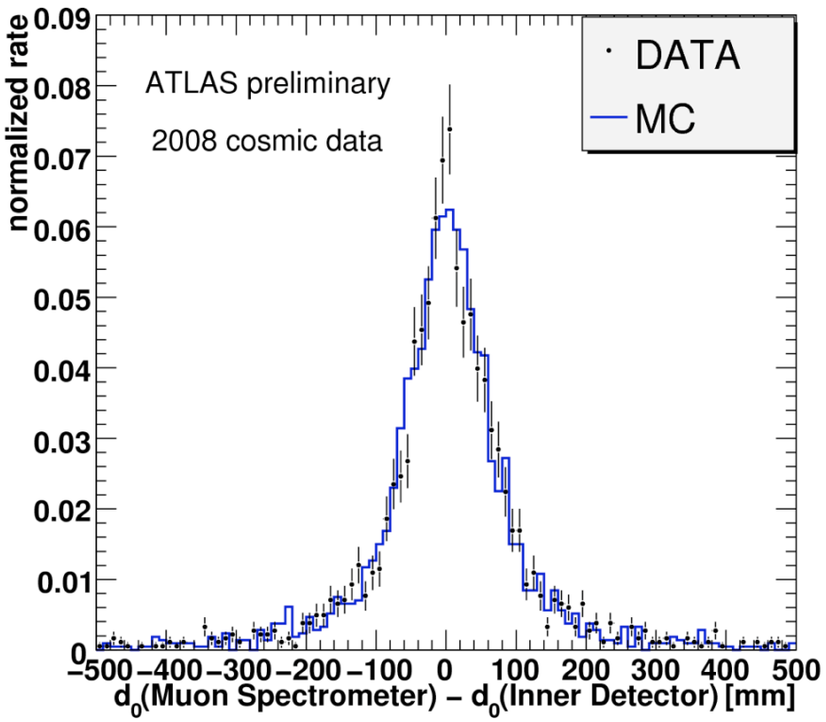




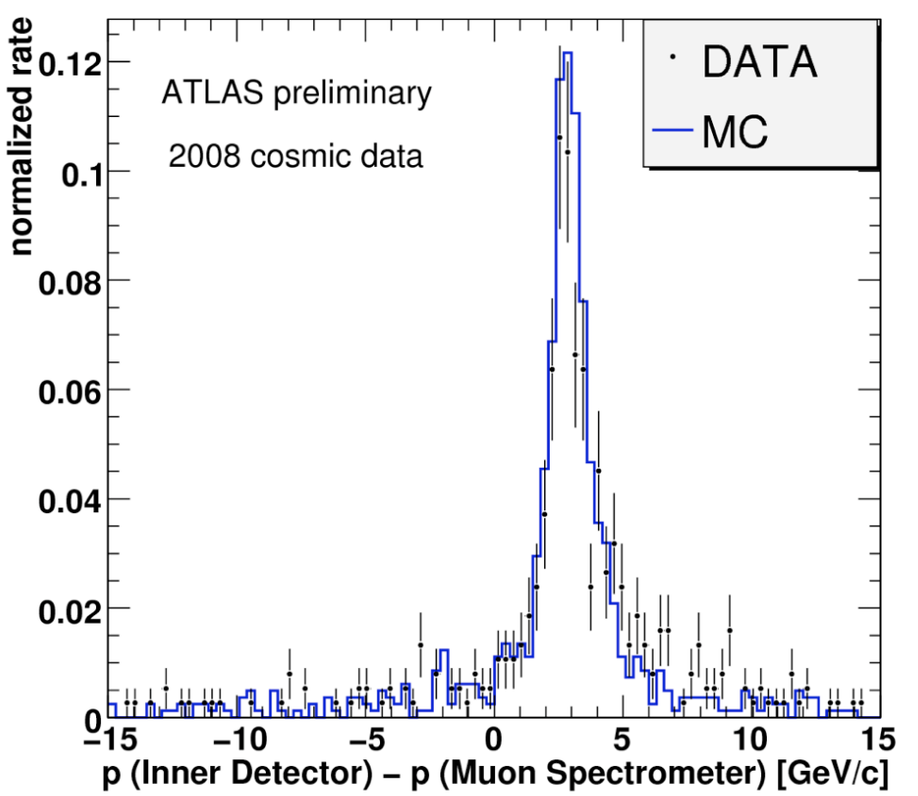
Combined muon reconstruction







- Clear correlation between track in Inner Detector and Muon Spectrometer
- Difference in track parameters in agreement with expectations from simulations
- Detailed studies comparing momentum difference with energy seen in calorimeters ongoing

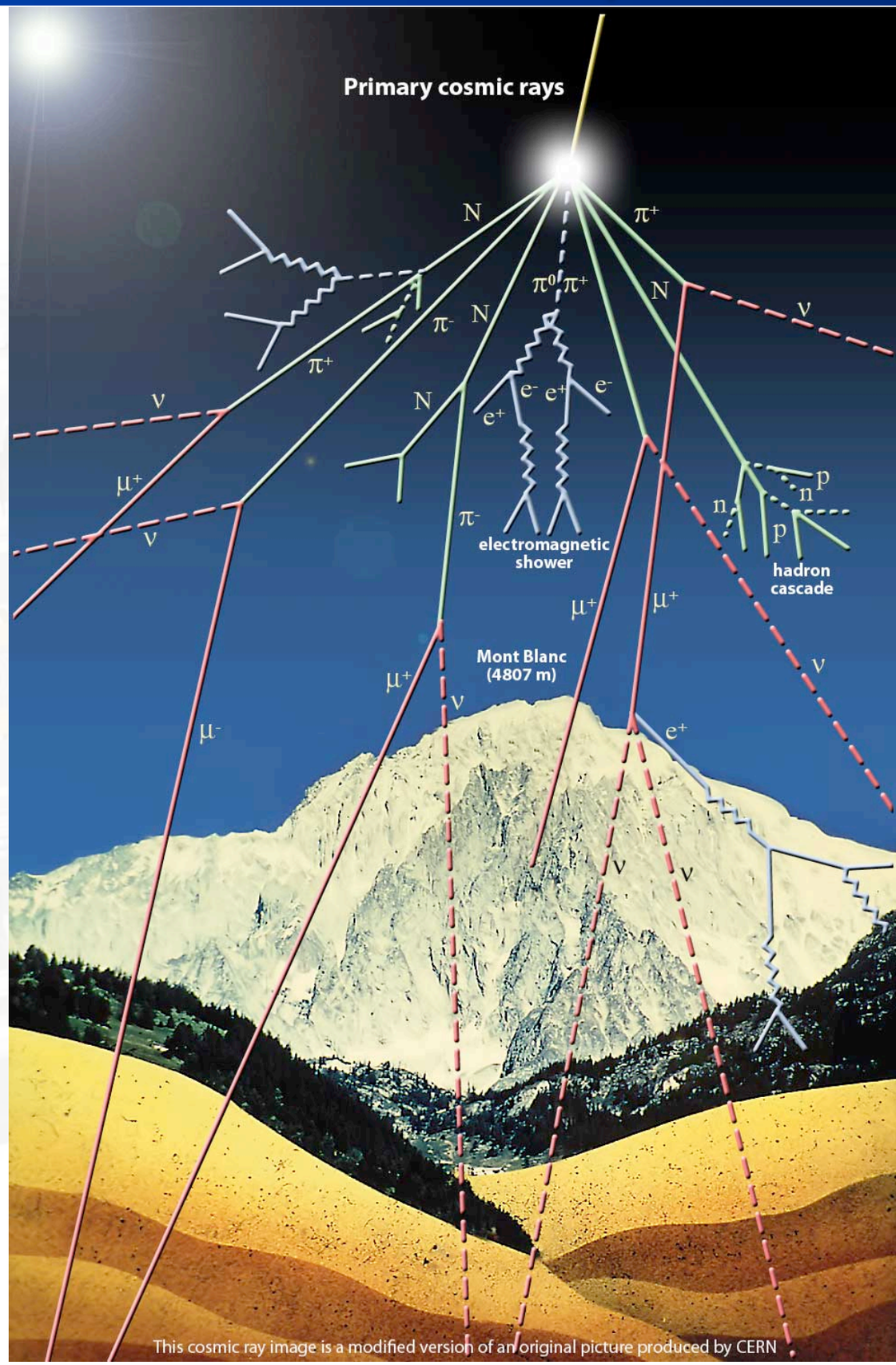


Summary

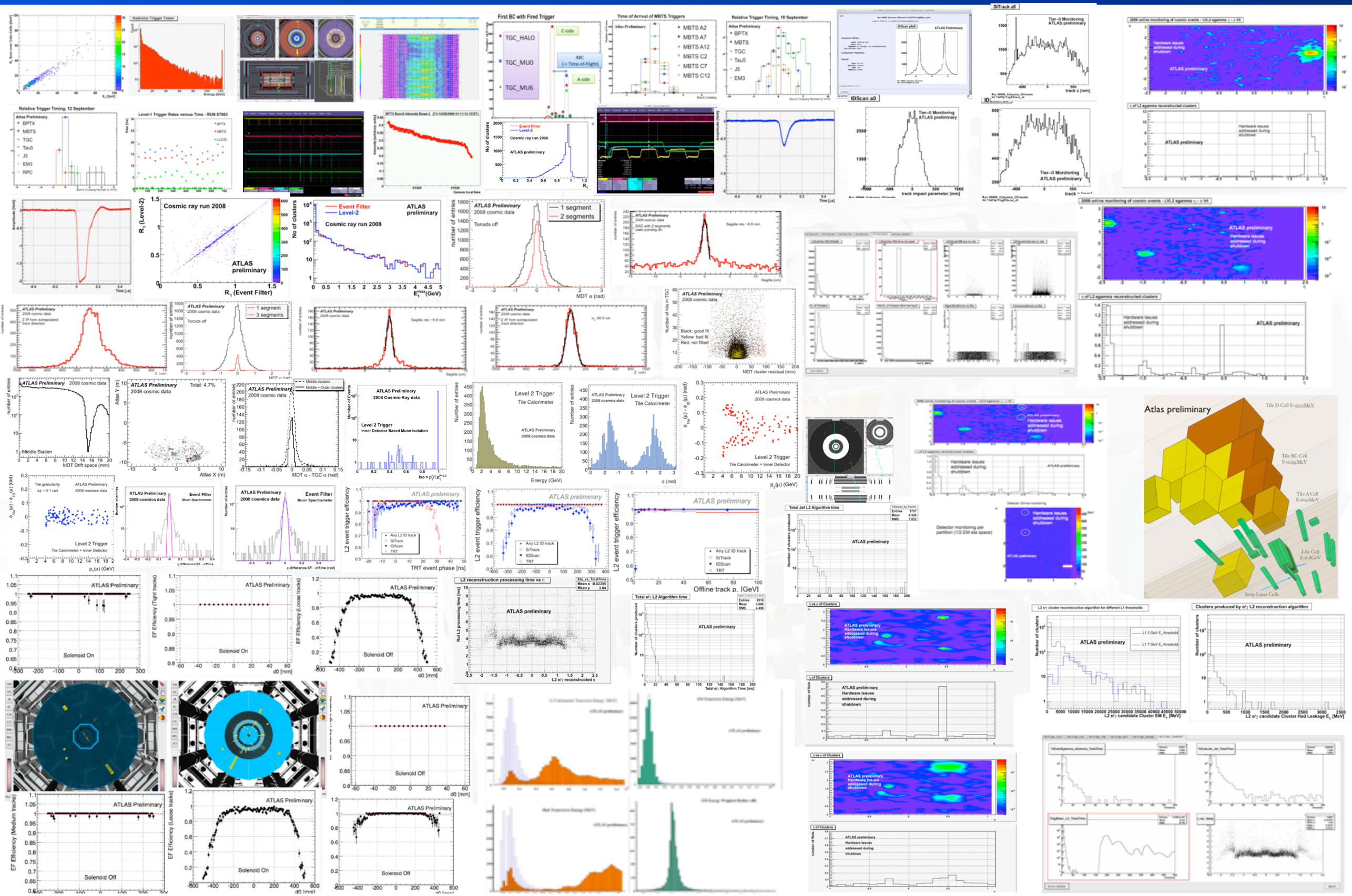
- More than 300 million cosmic events taken in Autumn 2008 and Summer 2009
- Data has been very useful in understanding the performance of the detector systems as well as the combined object performance, e.g.
  - Inner Detector track parameter resolution close to perfect detector
  - Missing energy well understood and stable over several weeks
  - First electrons have been seen in ATLAS!
  - Object identification and reconstruction well understood in cosmic events: good agreement between real data and simulation
- ATLAS well prepared for the restart of the LHC

Other talks at this conference with ATLAS cosmic ray results

- **Subdetector commissioning**
  - V. Perez Reale: Pixel Detector
  - A. Bocci: Transition Radiation Tracker
  - R. Hauser: Trigger/DAQ
  - A. Gibson: LAr Calorimeter
  - Y. Takahashi/S. Oda: Muon
- **Alignment**
  - B. Cooper: Inner Detector alignment
- **Object identification and reconstruction**
  - M.P. Casado: Tau trigger in cosmics
  - A. Ahmad: Electron and Photon ID



Collage of cosmic ray results (total O(200))



https://twiki.cern.ch/twiki/bin/view/Atlas/AtlasResults